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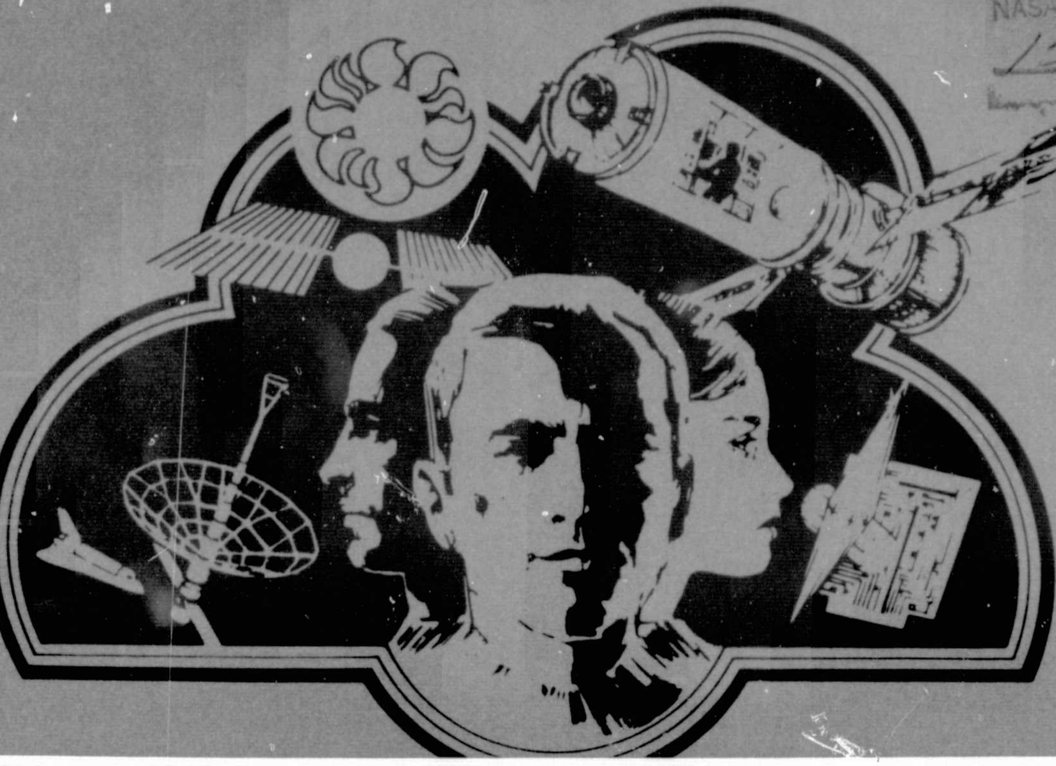

SPACE STATION SYSTEMS ANALYSIS STUDY
PART 3: DOCUMENTATION

VOLUME 2
Technical Report

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

CONTRACT NO. NAS 9-14958
DPD NO. 524
DR NO. MA-04

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CORPORATION

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PREFACE

The Space Station Systems Analysis Study is a 15-month effort (April 1976 to June 1977) to identify cost-effective Space Station systems options for a manned space facility capable of orderly growth with regard to both function and orbit location. The study activity has been organized into three parts. Part 1 was a 5-month effort to review candidate objectives, define implementation requirements, and evaluate potential program options in low earth orbit and in geosynchronous orbit. Part 2 was also a five-month effort to define and evaluate specific system options within the framework of the potential program options developed in Part 1.

Part 3, the last portion of this study, defines a series of program alternatives and refines associated system design concepts so that they satisfy the requirements of the low earth orbit program option in the most cost-effective manner.

The final reporting of the Part 3 study activity consists of the following:

- Volume 1, Executive Summary
- Volume 2, Technical Report
- Volume 3, Appendixes
  - Book 1, Supporting Data
  - Book 2, Supporting Data
- Volume 4, Supporting Research and Technology Report
- Volume 5, Cost and Schedules Data

A complete list of Parts 1 and 2 tables of contents are included for references in Volume 3, Book 2 in Section 17 of the appendix.

During this study, subcontract support was provided to the McDonnell Douglas Astronautics Company (MDAC) by TRW Systems Group, Aeronutronic Ford Corporation, the Raytheon Company, and Hamilton Standard.

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CONTENTS

GLOSSARY

BMS	Beam Mapping Satellite
BOL	Beginning of Life
C&W	Caution and Warning
CMG	Control Moment Gyro
CS	Construction Shack
DDT&E	Design, Development, Test, and Evaluation
DM	Docking Module
DOD	Depth of Discharge
ECLSS	Environmental Control/Life Support System
EMU	Extravehicular Mobility Unit
EOL	End of Life
ERB	Engineering Review Board
EVA	Extravehicular Activity
FOV	Field of View
G&N	Guidance and Navigation System
GN&CS	Guidance, Navigation and Control Subsystem
GPC	General Purpose Computer
HLLV	Heavy-Lift Launch Vehicle
IUS	Interim Upper Stage
MBL	Multibeam Lens
MDM	Multiplexer-Demultiplexer
MMS	Multimission Modular Spacecraft
MMU	Manned Maneuvering Unit
MPTS	Microwave Power Transmission System
OTV	Orbital Transfer Vehicle
PCM	Pulse Code Modulation
PIDA	Payload Installation and Deployment Aid
PM	Power Module
POS	Portable Oxygen System
PRS	Personnel Rescue Systems

RCP	Reaction Control Pod
RCS	Reaction Control System
RLSF	Regenerative Life Support Evaluation
RMS	Remote Manipulator System
SCB	Space Construction Base
SCM	Space Construction Module
SEPS	Solar Electrical Propulsion System
SPA	Space Processing Activity
SPDF	Space Processing Development Facility
SPS	Satellite Power System
SRB	Senior Review Board
STS	Shuttle Transportation System
TDRS	Tracking and Data Relay Satellite

Section 1
INTRODUCTION

The Space Station Systems Analysis Study was a 15-month effort divided into three parts. The first part of the study, which has been documented in MDAC Report G6508, involved selection of objectives, identification of mission hardware, description of program options and identification of program requirements. The second part of the study, which has been documented in MDAC Report G6715, involved selection of program options, definition of mission hardware and development of Space Construction Base (SCB) configurational concepts and system requirements. The last part of the study focused on definition of construction systems and development of an evolutionary program featuring a sequential growth of manned operations from Shuttle/Sortie support missions, advancing to Shuttle-tended missions and eventually transitioning to continuously manned SCB missions.

The study schedule shown in Figure 1-1 indicates when meetings were held with NASA. The Engineering Review Board (ERB) meetings were held to assure that the technical direction of the study was in agreement with NASA planning and requirements. The Senior Review Board (SRB) allowed NASA management to evaluate the progress of the study. Also indicated in the schedule are three important conferences which supported the technical efforts of the study. In October 1976, a meeting was held at JSC to discuss Solar Power Satellite (SPS) pilot plant sizing. This meeting reviewed the SPS development program and pilot plant requirements with the purpose of establishing basic pilot plant sizes and mission operations. Also, during October, a Space Processing Workshop was held by MDAC at Huntington Beach, California. The workshop provided a means to review the requirements for commercial space processing activities as transition is made from research-oriented to commercial-oriented spaceflight programs. A second conference was held by NASA in Houston, Texas in May, 1977. The purpose of the conference was to review space plasma effects and collectively answer specific questions relating to environmental problems in low earth orbit.

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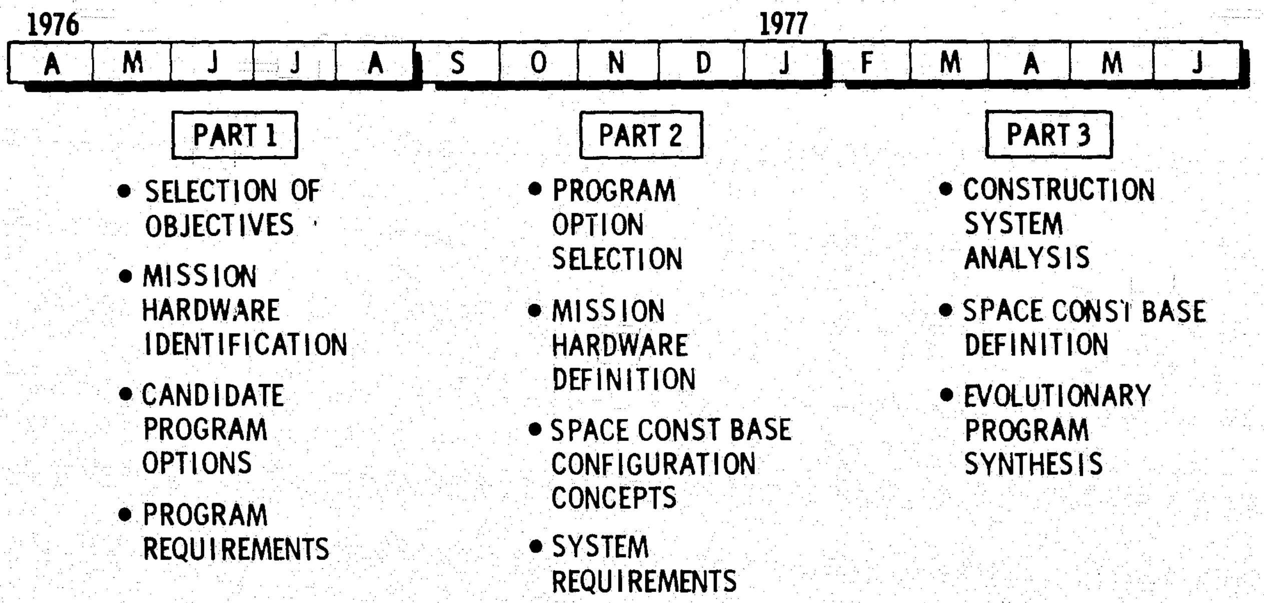

Figure 1-1. Space Station Systems Analysis Study

1.1 PART 1 SUMMARY

During Part 1, the initial step was to review the available background data on space objectives in order to select jointly with NASA a representative set of mission goals or objectives sufficient to describe the range and extent of the potential requirements which might reasonably be placed on a Space Station system. It was determined that the Outlook for Space report (NASA SP-386, January 1976), supplemented by data available through the study of the Commonality of Space Vehicle Applications to Future National Needs (Aerospace Contract NASW-2727), provided an excellent descriptive data base of key goals and objectives. This material was used to identify 47 program objectives exhibiting high benefit potential with requirements indicating manned space programs.

Because a manned Space Station system appeared to have the potential of contributing significant support in the near term, the 47 objectives were catagorized and eight were chosen (Table 1-1). The functional requirements associated with the chosen objectives were then used to establish the set of objective elements listed in Table 1-2.

Table 1-1

PART 1 OBJECTIVES

SPS	- Provide space facility for SPS feasibility tests
Earth Services	- Perform R&D on antenna construction
Space Processes	- Conduct R&D for commercial processing in space
MDSL	- Provide for multidiscipline research in space
Living and Working in Space	- Demonstrate long-term, productive residency in space
Orbital Depot	- Develop technology for LEO-GEO transportation systems
Space Cosmology	- Support stellar, solar, planetary, and seti activities
Sensor Development	- Provide a facility for sensor development, test, and calibration

Table 1-2

OBJECTIVE ELEMENTS

SPS
- Test article 1
- Test article 2
- Test article 3

Earth Services
- 30, 100, and 300m radiometers
- Multibeam lens antenna
- 3.75-km nav antenna

Space Processing
- Development
- Optimization
- Commercial process plants
- SI ribbon/blanket plant

Multidiscipline Laboratory
- Minimum level
- Maximum level

Living and Working in Space
- Limited research
- Extensive research
- Demonstration of techniques
- Construction support

Orbital Depot
- R&D for LEO - GEO transport system

Space Cosmology
- Component R&D
- MK II radio telescope

Sensor Development
- Development and test
- Fabrication and evaluation

The operational requirements for the various objective elements were then derived which, in turn, allowed the development of a broad spectrum of program options. Forty-five program options were defined that 1) covered a variety of combinations of objective elements, 2) required a broad range of program funding, 3) covered the various orbit regimes of interest, and 4) included growth elements such as the heavy-lift launch vehicle (HLLV) and orbital transfer vehicles (OTVs).

A systematic evaluation of the options was performed utilizing four independent evaluation criteria (illustrated in Figure 1-2) as a means of discriminating one option from another. The first criterion was level of achievement, defined as the percentage of the total number of objective elements included within a particular option.

The second criterion, complexity, was a subjective evaluation of the options.

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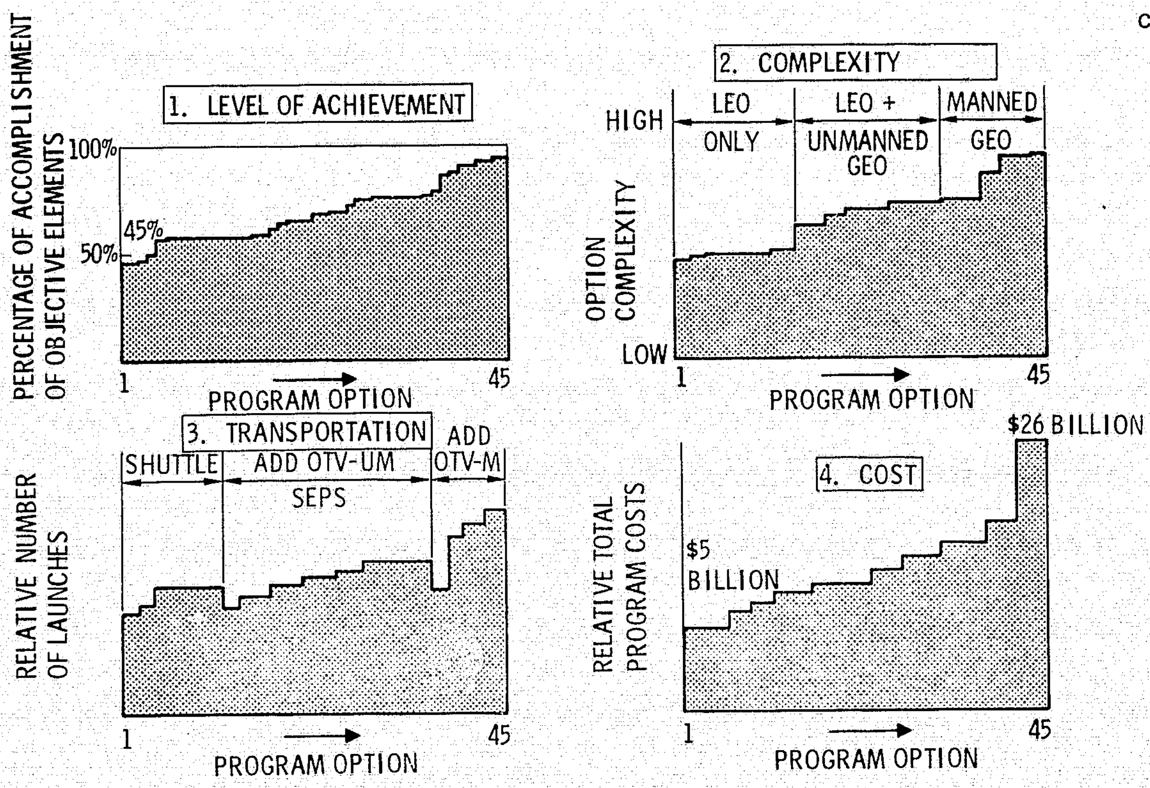

Figure 1-2. Program Option Categorization Criteria

The third criterion, transportation, was defined as the relative number of launches and types of launch vehicles required to support the options. The fourth and last criterion, cost, was the individual total relative program cost for each of the 45 options.

The study revealed that the fourfold evaluation scheme was most effective in distinguishing the similarities and differences among the options. As a result, a selection was made, with the concurrence of NASA, of four program options for further definition in Part 2. These options contained, in various combinations, the various objective elements and were defined as: Option L - manned operations limited to low earth orbit (LEO); Option LG1 - manned operations performed in LEO with some test operations in geosynchronous earth orbit (GEO) of hardware that was constructed in LEO; Option LG2 - operations in LEO with some construction as well as test operations performed in GEO; and Option G - manned operations including construction entirely in GEO.

1.2 PART 2 SUMMARY

The four program options from Part 1 were used as the basis for establishing Space Station system options capable of satisfying the mission requirements of the program options. The MDAC and NASA concurred that the most beneficial approach in Part 2 would be to concentrate on program option L expanded to include two operational modes (Figure 1-3):

- Early Shuttle-tended operations, during which elements of a continuously manned SCB are used only while the Orbiter is present. Subsequently, when a full SCB is assembled and activated, the Shuttle continues to supply logistic support.
- Construction and activation of a full SCB prior to operations.

Either of these modes was found to be viable, with a significant early cost/schedule advantage for the Shuttle-tended mode.

The Shuttle-tended concept can provide an early space construction fabrication and assembly capability only, or it can be expanded to include science and space processing development activities. Crew requirements are compatible with the Shuttle support capability of up to seven SCB crewmen.

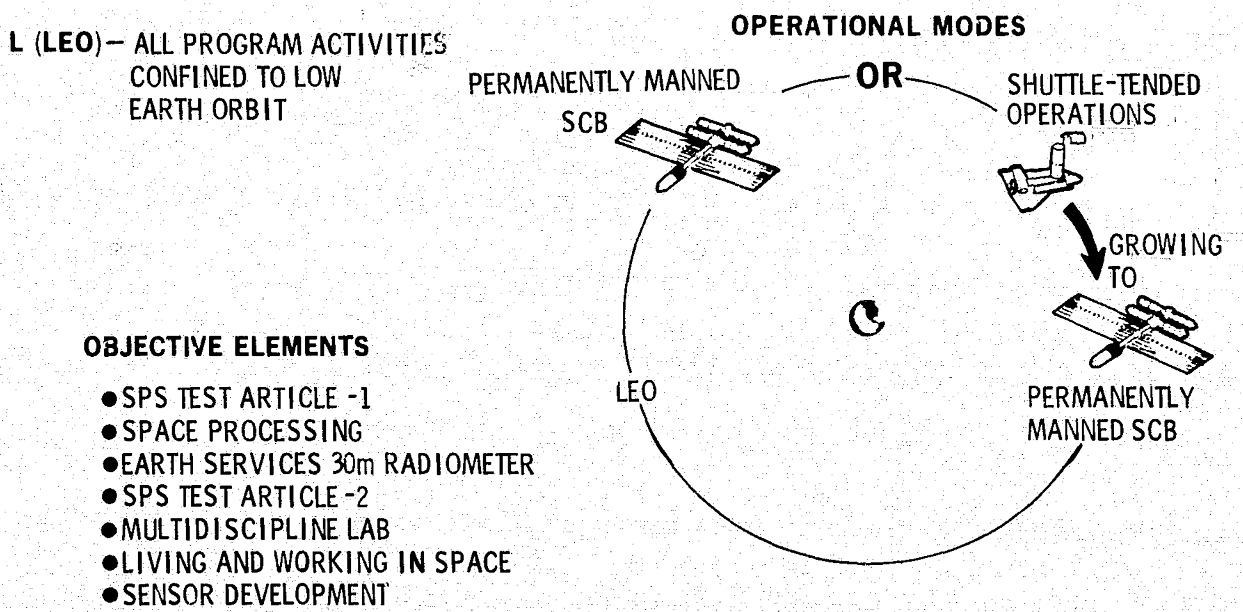

Figure 1-3. Program Option L

Fabrication and assembly operations require three crewmen, a crew size which is sufficient to conduct other activities such as space processing development tasks. The Orbiter commander and pilot are available to act in the capacity of SCB/Orbiter operational crew.

In Part 2 the continuous operation approach to the SCB was based on previous Phase B Space Station studies. Thus, for the seven-man crew, two crew accommodation modules and a logistics module are required in addition to those required by the Shuttle-tended configuration. In this mode, the crew is continuously available, with rotation taking place on 90- to 180-day periods. During the initial operational phase, a single solar array power module supplies sufficient power to accomplish a broad spectrum of objectives in space construction (e.g., 30m radiometer, SPS TA-1 and SPS TA-2) and space processing. Growth to a 14-man crew requires additional crew, core, and power modules.

Also, the commonality of operational requirements identified in Part 2 which was necessary to successfully complete various objective elements, results in a desirable synergism in cost savings throughout the overall SCB program. In Figure 1-4, major requirements for a particular objective element are indicated by a large check (✔); minor requirements by a small check mark (✓). For example, all objective elements require crane operations either to a major or minor extent. Crane operations are a major requirement in the fabrication and assembly of SPS TA-1, TA-2, and a 30m radiometer. In contrast, the laboratory-type elements basically necessitate crane operations only initially to position the module or to supply necessary materials. Also, all elements could provide useful functions throughout a long time period, although for the basic laboratory-type objective elements, longer duration operations are more strongly implied than for the fabrication-and-assembly oriented objective elements. Data to support the objective of living and working in space will, of course, be derived from the performance of all operations.

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OBJECTIVE ELEMENT	CRANE OPERATIONS	SPACE FABRICATION	SPACE ASSEMBLY	EVA REQUIREMENTS	LONG DURATION
TEST ARTICLE-1	✔	✔	✔	✔	✓
TEST ARTICLE-2	✔	✔	✔	✔	✓
30m RADIOMETER ANTENNAS	✔	✓	✔	✔	✓
SPACE PROCESSING	✓				✔
MULTIDISCIPLINE LABORATORY	✓			✓	✔
LIVING AND WORKING IN SPACE	✓	✓	✓	✓	✔
SENSOR DEVELOPMENT AND TEST	✓		✓	✓	✔

Figure 1-4. Several Objective Elements Yield Common Requirements

Figure 1-5 shows configurations of the Shuttle-tended SCB (i. e., the Shuttle provides on-station support and life support services for the four- to seven-man fabrication and assembly crew). Addition of the previously mentioned modules allows for continuous operations. With the addition of other modules, such as those for bioprocessing and shaped-crystal processing, the station can support a multidisciplinary program.

At the conclusion of Part 2, an evaluation of the system options under consideration revealed that utilization of the Shuttle-tended mode is beneficial in the early phases; as mission requirements increase, the continuous operations mode becomes cost effective.

Figure 1-6 summarizes the mission durations, payload weight, crew sizes, power, orbital regimes, and manhours per year, which are best provided in the Shuttle-tended and continuous operations modes. Areas of capability overlap are also indicated. The final program plan developed for the 1980's

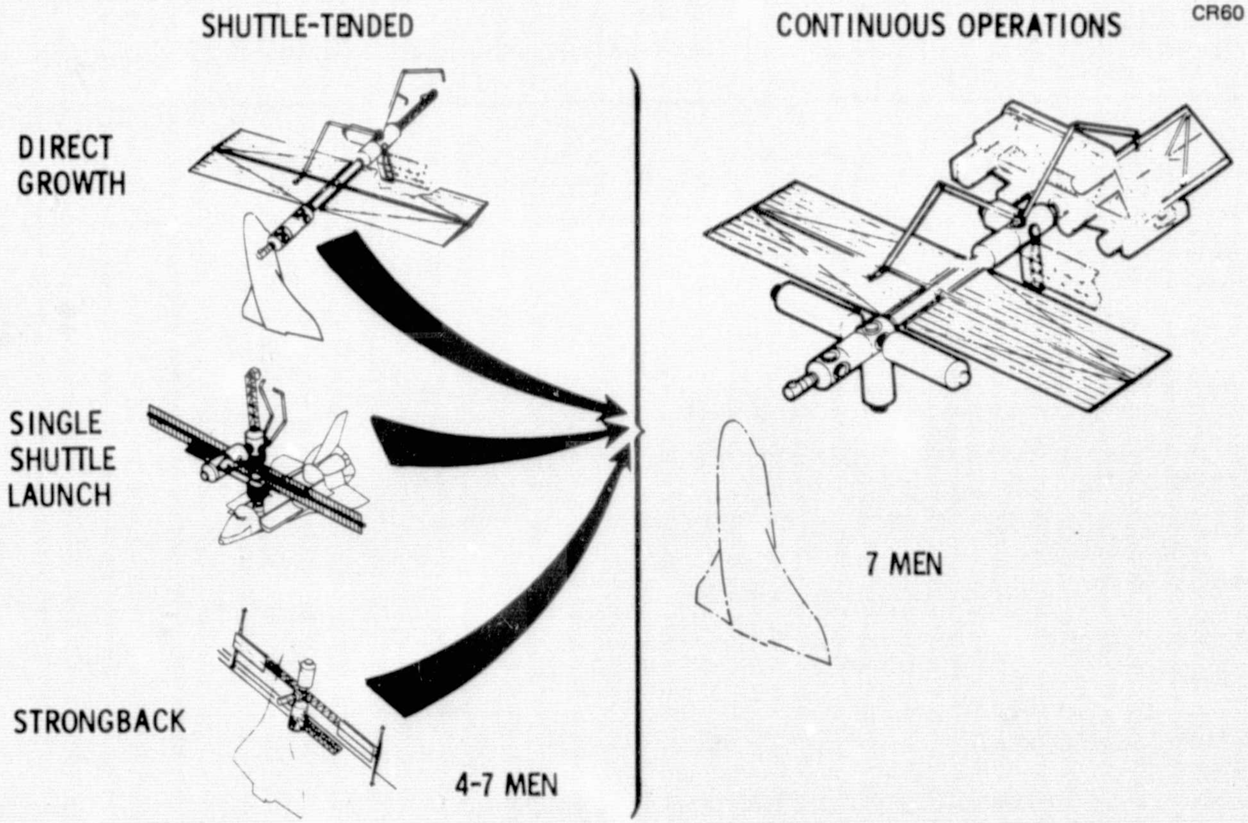

Figure 1-5. SCB Configuration Concepts

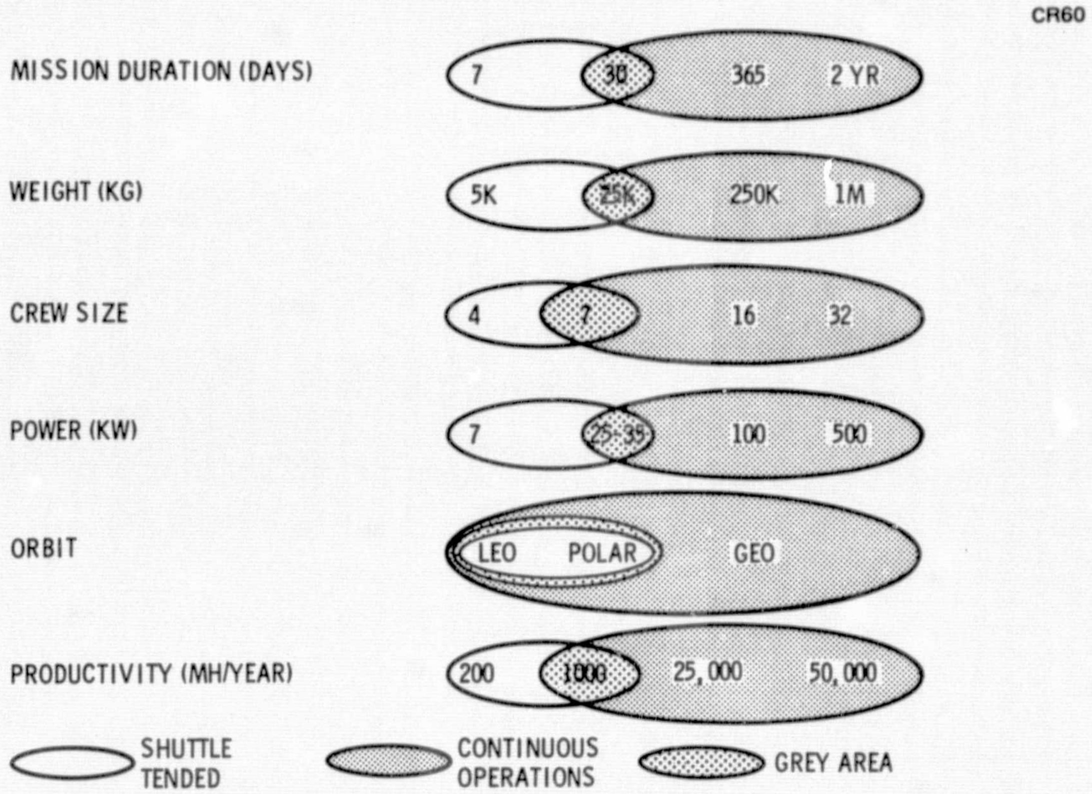

Figure 1-6. Shuttle/Space Station Operating Regimes

must achieve an optimal balance of the potential capabilities that will be available.

With recognition of funding constraints, that portion of the total program objectives which can be fulfilled using the Shuttle-tended mode of operation was chosen for the initial phases of the program for Part 3, and emphasis was placed on SPS and earth services. Also, a primary objective established for the Part 3 work was to simplify and reduce the number of modules (and cost) required to support currently defined objectives both initially and in the growth configurations.

Section 2
SUMMARY OF PART 3

Part 3 of the study was largely an analysis of the construction operations including reexamination of power requirements and power systems, further definition of mission hardware requirements and design concepts, an expanded definition of the SCB configuration in conjunction with additional reduction in the number of modules, and an evolutionary program definition which features a sequential growth of manned operations from Shuttle/Sortie support missions, advancing to Shuttle-tended missions and eventually transitioning to continuously manned SCB missions.

2.1 CONSTRUCTION OPERATIONS ANALYSIS

The primary objective of the construction operations analysis was to establish the feasibility of a basic construction concept and to develop data which would allow comparisons of other construction concepts. The procedure followed in analyzing the construction operations (Figure 2-1) was first to take the preliminary design and construction concepts for each item of mission hardware and develop the packaging approach in conjunction with how the part would be constructed. Detailed flow logic was then developed, with each step providing a logical sequel to its immediate predecessor. After an acceptable flow was achieved, each event was analyzed to determine how long it would take, how much extravehicular activity (EVA) translation distance would be involved, the required crane reach, and similar contributing factors. These data were then compiled into timelines and the associated requirements summarized.

The study has concluded that there are two basically different approaches to space construction. The first is characterized by a fixed work station where the parts are moved to the work station. This approach is similar to production assembly line operations in factories where the material flows and the process machinery remains stationary.

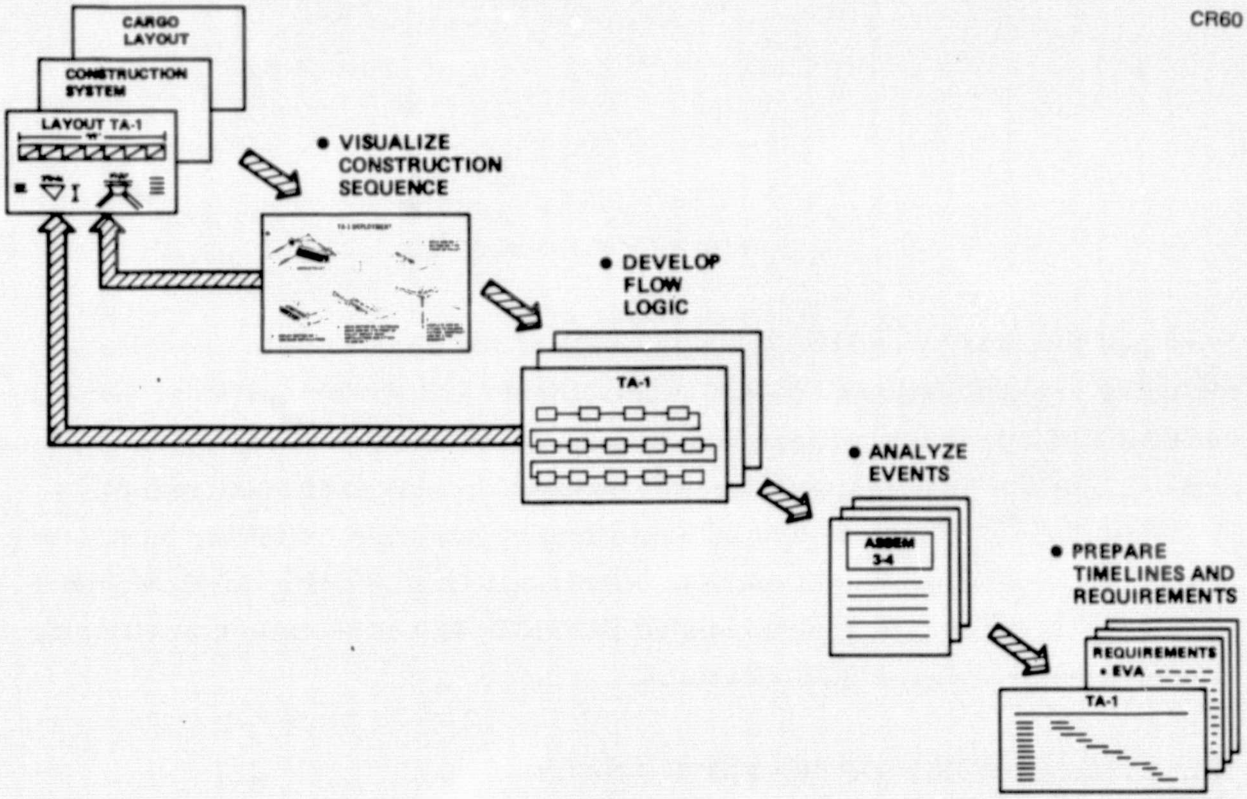

Figure 2-1. Construction Operations Analysis

The second construction approach is characterized by a traveling work station which is transported to the work. Analogies in ground-based work are found in construction of ships and buildings where the site of the construction is a fixed geographical location and cannot be moved.

This study has concluded that, in a zero-g environment, the fixed work concept provides the most efficient approach and results in a lower SCB weight, a less costly construction system, and a substantial reduction in total effort. Also, space construction, though it presents a technical challenge, appears to be achievable within the current state of the art, and the SCB defined by the study can be a cost effective approach to satisfying future requirements in space.

2.2 POWER SYSTEM SIZING

Power requirements and the solar arrays or power modules to satisfy these requirements are important considerations in the buildup sequence of various hardware items and in constructing the objective elements. These consider-

ations were addressed in detail in the Part 3 study. The microwave power transmission system (MPTS) test article associated with the development of the SPS program resulted in a requirement for about a 450 kW power level for test. The cost effectiveness of building such a power supply, as opposed to one sized by activities other than SPS, was investigated. Since the 450 kW power level is much greater than needed for any non-SPS program considered, power levels that could support other objectives were considered, and these levels were assessed with respect to the SPS test program.

Important factors in these considerations were cost, drag and attitude control requirements and orientation schemes. The result of the analyses revealed that a 250 kW level appears to be a reasonable level resulting as a compromise among competing considerations.

If the high power requirements associated with the testing of TA-2 are deleted from power system sizing, then a smaller power module can be considered. Taking the requirements for the Space Construction Base (including the Orbiter in a Shuttle-tended mode) and the requirements for various possible objective elements, and adding a contingency margin, one finds that a long term program with a variety of possible combinations of activities can be supported by a power module having an average power output around 38 kW. A minimum level appears to be about 25 kW. At this level, all activities can be supported, though generally only one at a time.

2.3 MISSION HARDWARE REQUIREMENTS

A summary of mission hardware examined in Parts 2 and 3 is given in Figure 2-2. Work during Part 3 consisted of a reexamination of SPS and Space Processing functional requirements (with particular attention to reduction of early Mission Hardware costs) and a more detailed examination of two facets of SPS requirements (on-orbit MPTS test requirements and high voltage plasma leakage affects on solar cell arrays in LEO).

Table 2-1 summarizes early SPS test requirements as derived in Part 2 of the study and indicates the applicability of specific test articles.

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MISSION HARDWARE	SPACE CONSTRUCTION TASKS		
	FABRICATION AND ASSEMBLY	ASSEMBLY	DEPLOY
SPS TEST ARTICLE 1	✓		(▲)
SPS TEST ARTICLE 2			
SOLAR COLLECTOR	✓	▲	▲
ANTENNA	✓	▲	(▲)
LARGE POWER PLATFORM	(▲)	▲	▲
30M RADIOMETER	✓	✓	
100M RADIOMETER		(▲)	
MBL ANTENNA	✓	▲	

✓ PART 2 ▲ PART 3 ○ EMPHASIZED IN PART 3

Figure 2-2. Construction Related Objective Elements

A review of cost information developed in Part 2 indicated that much of the investment in SPS test articles was due to the automated assembly requirements. For this reason it was decided to derive new TA-2 design and construction concepts that could utilize less expensive tooling. To allow comparative costing, this effort was expanded to include new solar collector concepts in each of the three major areas of space construction technique (fabricate and assemble, assemble only, and deployable). These are further described in Section 4 of this report.

Examination of space processing requirements in Part 2 revealed that in order to provide a transition from short-duration Spacelab missions to long-term operations involving dedicated modules, a general-purpose space-processing facility capable of supporting multiple users is needed. Accordingly, a Space Processing Development Facility (SPDF) module was derived from Orbiter, Spacelab, and payloads for Spacelab equipment programs.

Table 2-1

SPS TEST ARTICLE REQUIREMENTS MATRIX

Summary Development Requirements	SCB Development Test Article TA-1L	TA-1G	TA-2
1. Evaluate space construction of large structures			
A. Solar collector			X
B. Microwave antenna	X	X	X
C. Structural interfaces	P	P	X
2. Evaluate large-scale energy collection and distribution			
A. 20,000 V			X
B. Switching			X
3. Evaluate large-scale microwave transmission and phase control			
A. Ionospheric degradation of phase control system		X	
B. Thermostructural effects on phase control system	X	X	X
4. Evaluate RFI effects of energy transfer			
A. Direct transmission from amplitrons	X	X	X
B. Switching and rotary joint sources	X	P	X
C. Voltage-level regulation	P	P	X
D. Ionosphere-induced		X	
5. High voltage and space plasma interactions			
A. Arcing and leakage	X	X	X
B. Spacecraft charge phenomena		X	
6. End-to-end functional verification			
A. Thermal/structural interaction	P		X
B. Phase control system	X		X
C. Power transfer/rotary joint current density			X

P = Partial satisfaction

The spaceflight activities planned for the facility would involve missions ranging from 30 to 90 days in duration. During this mission processes suitable for production, as contrasted to purely scientific research, would be evaluated. Emphasis would be directed to demonstrating repeatability, quantity, uniformity, and efficiency parameters that are crucial to attract commercial interests to space processing.

Also in Part 3, examination of requirements associated with radiometry revealed the necessity of complementing the 30 radiometer defined in Part 2 with a 100m radiometer designed to operate in the low frequency band of interest. Such a radiometer was defined.

2.4 MISSION HARDWARE DESIGN AND CONSTRUCTION

The MDAC approach to mission hardware followed classical system engineering lines: (1) determine mission requirements, (2) develop the design concept to fulfill the requirements, and (3) identify the minimum orbital construction equipment required to produce the hardware.

While demonstration of construction techniques and capability was considered to be a requirement, "demonstration" was not considered to be, in itself, sufficient justification for undertaking a space construction project. All mission hardware studied in MDAC's Space Station System Analysis Study had a prime objective other than demonstration of construction capability. For example, large solar collectors were intended to power microwave power transmission system (MPTS) development tests. Hence, all mission hardware has long-term usefulness, and no throwaway items were considered.

Design of any structure must include consideration of the production process. Typically, the structural designer starts his task with well understood construction process options. This is, of course, not true in space construction. Hence, synthesis of design and construction processes proceeded simultaneously in this study.

To allow comparative costing of fundamentally different approaches to construction, different designs have been conceived to meet identical functional requirements, as indicated in Figure 2-3. This figure also indicates the

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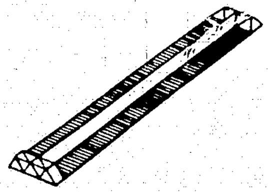
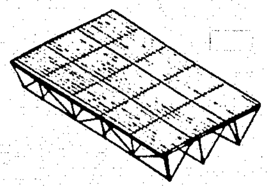
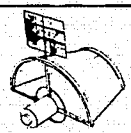
	SIZE	TYPE	NO. OF CONCEPTS*
 SOLAR COLLECTORS	38 KW_e AVG	DEPLOY AND ASSEMBLE	1
	150 - 500 KW_e RANGE OF COLLECTOR OUTPUTS	DEPLOY ONLY DEPLOY AND ASSEMBLE ASSEMBLE ONLY ✓ AUTOMATIC FABRICATION AND ASSEMBLY	1 3 1 2
	1720 KW_{RF}	AUTOMATIC ASSEMBLY	1
	17,100 KW_{RF}	AUTOMATIC ASSEMBLY	1
 MPTS ANTENNAS	80M LINEAR	FABRICATION AND ASSEMBLE	2
	126M CROSS (TA-1)	DEPLOY AND ASSEMBLE ASSEMBLE ONLY AUTOMATIC FABRICATION AND ASSEMBLY	1 1 1
	9M x 15M ARRAY (TA-2)	✓ DEPLOY AND ASSEMBLE ASSEMBLE ONLY AUTOMATIC FABRICATION AND ASSEMBLY	1 1 1
MULTIBEAM LENS ANTENNA 	27M	FABRICATION AND ASSEMBLE ASSEMBLE ONLY	1 1
RADIOMETER 	30M	ASSEMBLE ONLY	1
	100M	✓ ASSEMBLE ONLY	1
			22

*INCLUDING LAYOUTS, WEIGHT ESTIMATE AND CONSTRUCTION PROCESS CONCEPT LAYOUTS

Figure 2-3. Construction Study Spectrum Mission Hardware

total scope of mission hardware examined in all three parts of the Space Station Systems Analysis Study.

The MDAC approach to identifying construction equipment in Part 3 of the study was biased to favor reduced initial costs. Tooling was designed primarily to accomplish the immediate objectives. Additionally, mission hardware objectives were intentionally selected to provide different construction requirements. Hence, there was little opportunity to develop tooling commonality between objectives. However, in Part 2 of the study, common fabrication and automation assembly equipment was identified for one version of TA-1 and TA-2.

2.5 DEFINITION OF SCB CONCEPTS

Also in Part 3 of the study, several candidate space construction base concepts were defined and compared. The specific design tasks in Part 3 are illustrated in Figure 2-4.

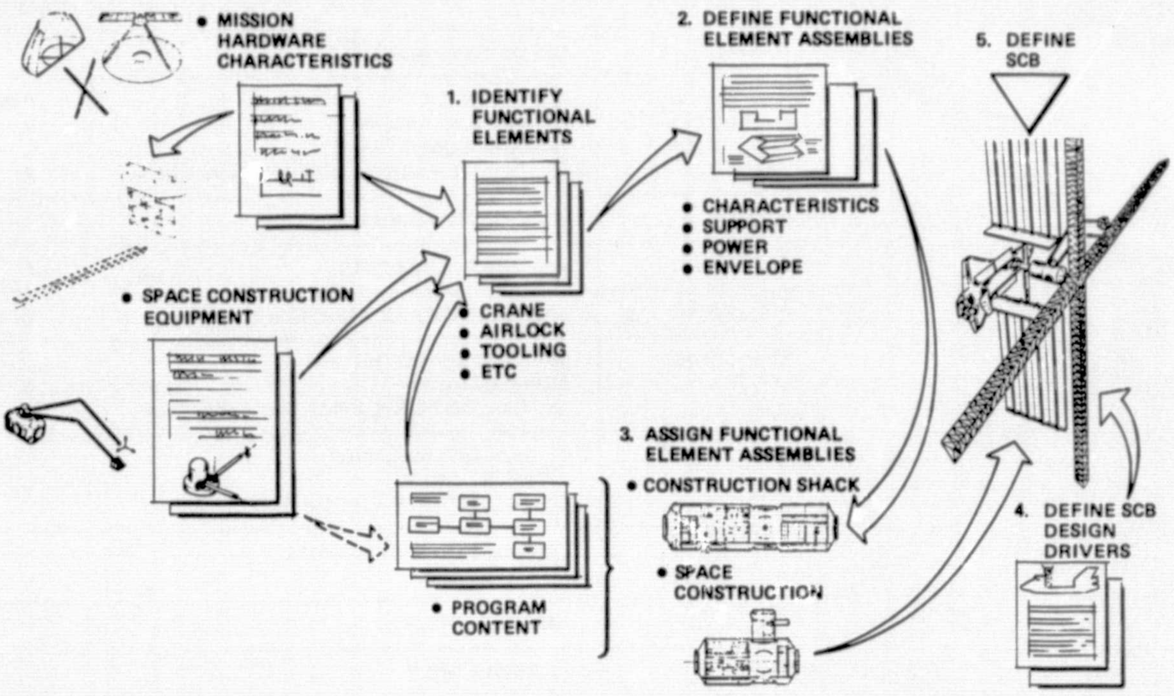


Figure 2-4. Part 3 SCB Concept Development

A major factor in the SCB concept development was the definition of important subsystem and operational design drivers. This was accomplished by first identifying all functional elements of the SCB. In this case, a functional element consists, for example, of an internal component of the module, operating equipment, or a subsystem component. These functional elements were then listed on data sheets summarizing their physical characteristics, power requirements, and other pertinent quantitative information which would influence their subsequent location within the SCB. The data sheets were then used together with operational requirements to allocate the various items and permit volume and mass allocations for each module.

Outboard configuration development was approached in a similar manner. The operations and subsystem functions which significantly influenced the SCB configuration were identified and used to evaluate several candidate configurations. These items included, for example, orbiter docking requirements, logistics and emergency considerations, construction working envelopes, and drag makeup propellant requirements.

After evaluation of the candidate configurations, the selected ones were checked to assure that they were consistent with the functional and operational requirements of all aspects of the program.

Two SCB configurations were identified to satisfy the two orbital operational modes which were evaluated in the study. These operational modes are: (1) Shuttle-tended, in which the Orbiter provides all crew support and a major share of the SCB's operational support and (2) continuously manned, in which the Orbiter supplies only the launch transportation and periodically is docked to the SCB for several days to transfer crew, cargo, and consumables.

In the initial operations configuration a Space Construction Module (SCM) of the SCB has been designed, which is compatible with operation in a Shuttle-tended mode and provides the control, crane, shop and operations support functions for construction and test activities (Figure 2-5). An initial free-flying Power Module concept has been derived which is also compatible with this mode of operation. The Power Module is delivered in a single Shuttle launch and the solar arrays deployed. The SCM is delivered on a subsequent launch. The Shuttle docks to the Power Module and berths the SCM to the Power Module, and the crane is erected (Figure 2-5).

The SCB configured in its later stages of development for continuous operations employs two basic modules adding a Construction Shack Module to the Space Construction Module. The Construction Shack Module acts as the central control for continuous operations and also provides a habitat for up to seven crewmen (Figure 2-6).

A candidate construction system for the SCB features a strongback standoff. The strongback provides a convenient structure for support of both a power platform and the propulsion system necessary to stabilize the final SCB.

With the power platform constructed and installed, the other end of the strongback can be used in conjunction with a turntable for construction of the other items of mission hardware, such as the 30m radiometer. Larger mission hardware, such as the 100m radiometer, can be built on the strongback, using its telescoping feature to move the part relative to the work station.

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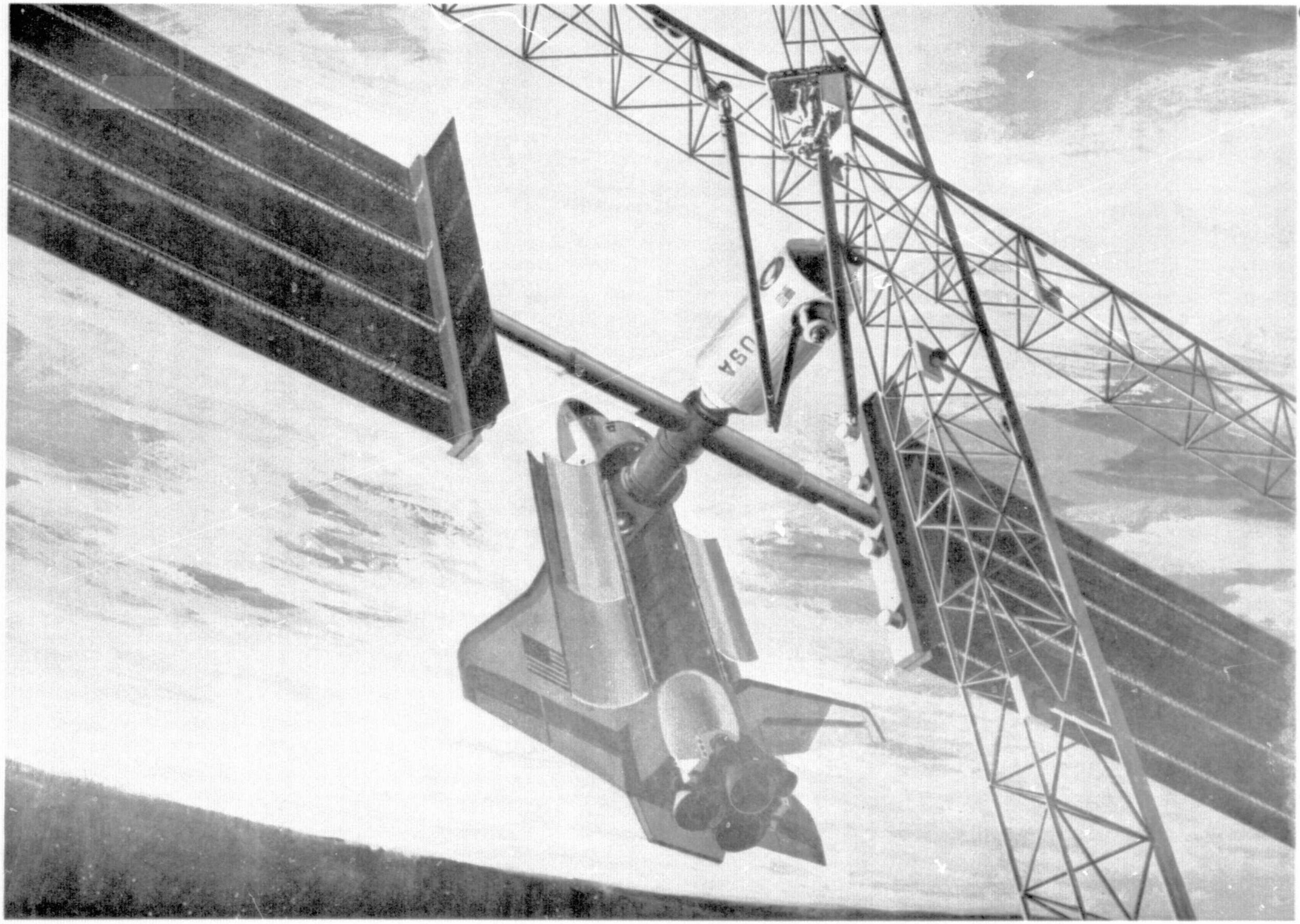

Figure 2-5. Initial Operations Configuration

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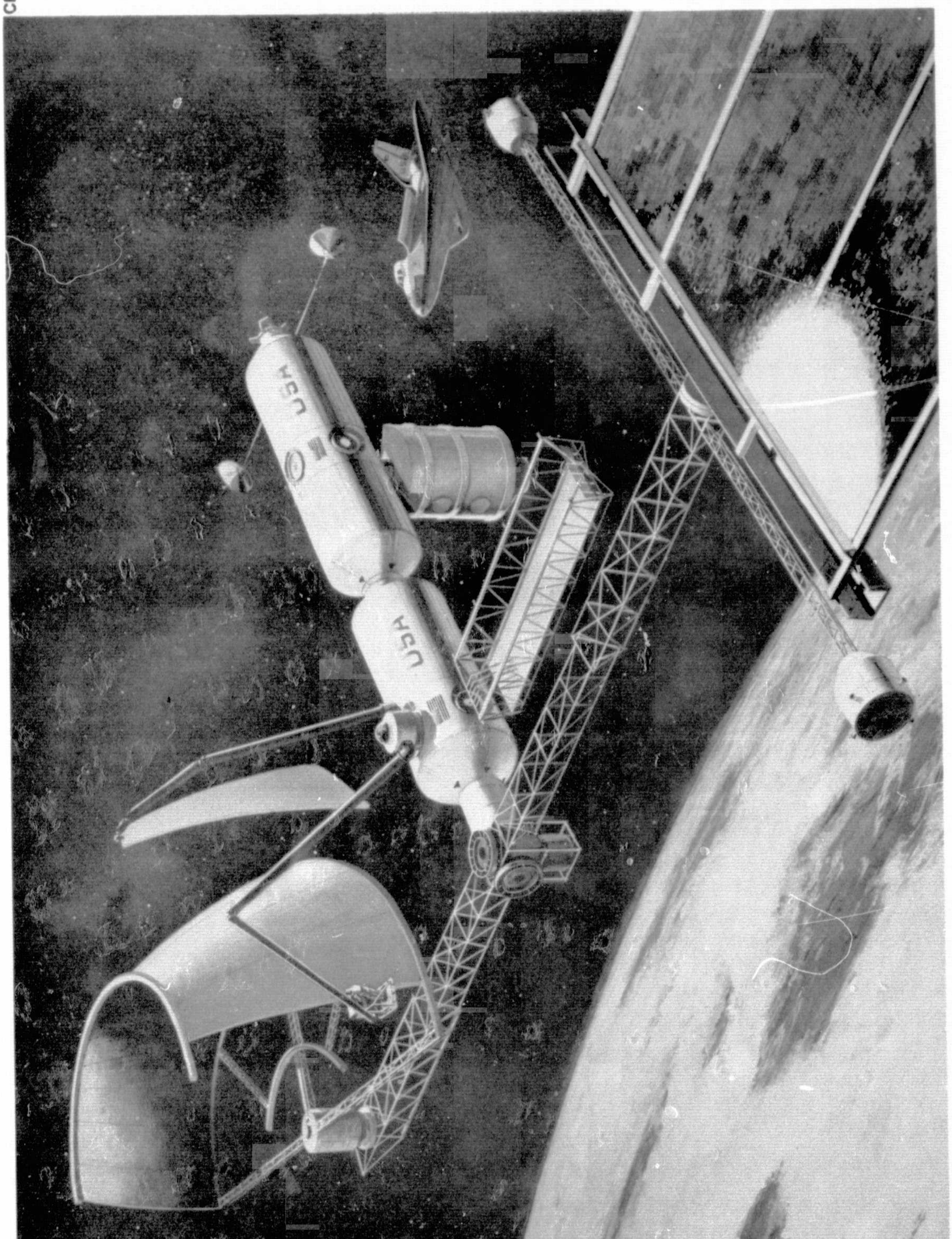

Figure 2-6. Continuous Operations Configuration

Modules for support of activities such as space processing or scientific investigations can be berthed at ports on the Construction Shack Module.

2.6 EVOLUTIONARY PROGRAM DEFINITION

The concept of evolving from Shuttle-tended operations to continuous manned operations dictates the need for a planned transition program. A logical evolution of the SCB incorporates an orderly transition from the Shuttle transportation system (STS) and Shuttle-tended operations to continuous operations configurations (Figure 2-7).

After the basic construction-related technology development flights have been undertaken, the first step is an increase in available on-orbit electrical power. This step, which is necessary to support Spacelab missions, could support early activities associated with SPS and earth services objective elements and science and/or space processing research missions. At this point in the program, the introduction of the Space Construction Module would provide, in a Shuttle-tended mode, the first significant operational construction capability.

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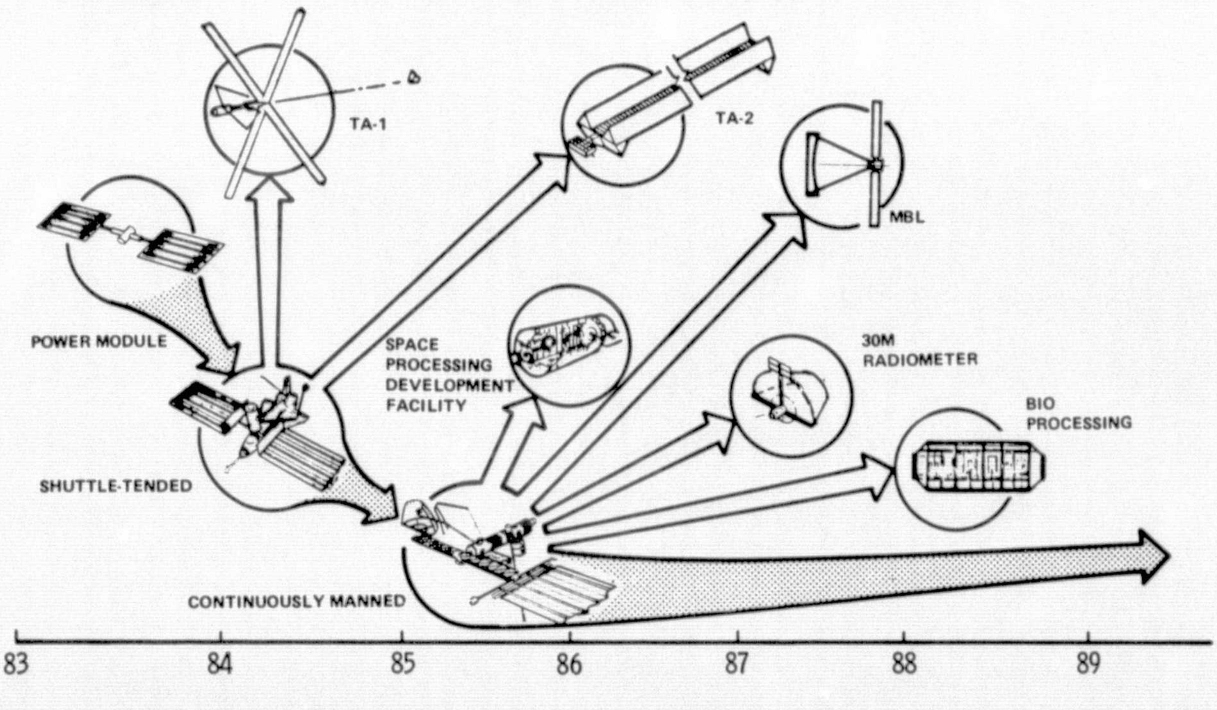

Figure 2-7. Products of Evolution

As the complexity and sizes of the objective elements increase, extended on-orbit capabilities will be required, and a Construction Shack to provide habitation outside of the Orbiter and a large power platform to provide increased supplies of electrical energy could be added. This evolutionary step could advance the autonomy of the Space Construction Base to the point where continuously manned operations would be available to keep pace with the expanding workloads. Objective elements, such as the Space Processing Development Facility, could be supported as well as the conduct of SPS development tests. The next advance in capability would involve support, on a continuous basis, of commercial space processing production development, multipurpose science missions, large scale construction and productivity demonstrations, and development of the capability to conduct manned operations at GEO.

Throughout the steps of the program, the pace and order of introduction of the elements of the SCB involve trades of timely cost-avoidance alternatives versus longer range system options which may be more costly initially but due to more efficient operations, could eventually result in a lower total program cost.

Figure 2-8 depicts a typical sequence of objective element activities for the SCB. It should be noted, however, that the SCB developed in this study is not sensitive to the order in which specific tasks are accomplished, due to the flexibility and growth features of the concept.

The particular sequence shown emphasizes early SPS test article construction and testing. Other sequences which would accomplish space processing development and optimization as the initial activities could just as easily be supported by the SCB concept.

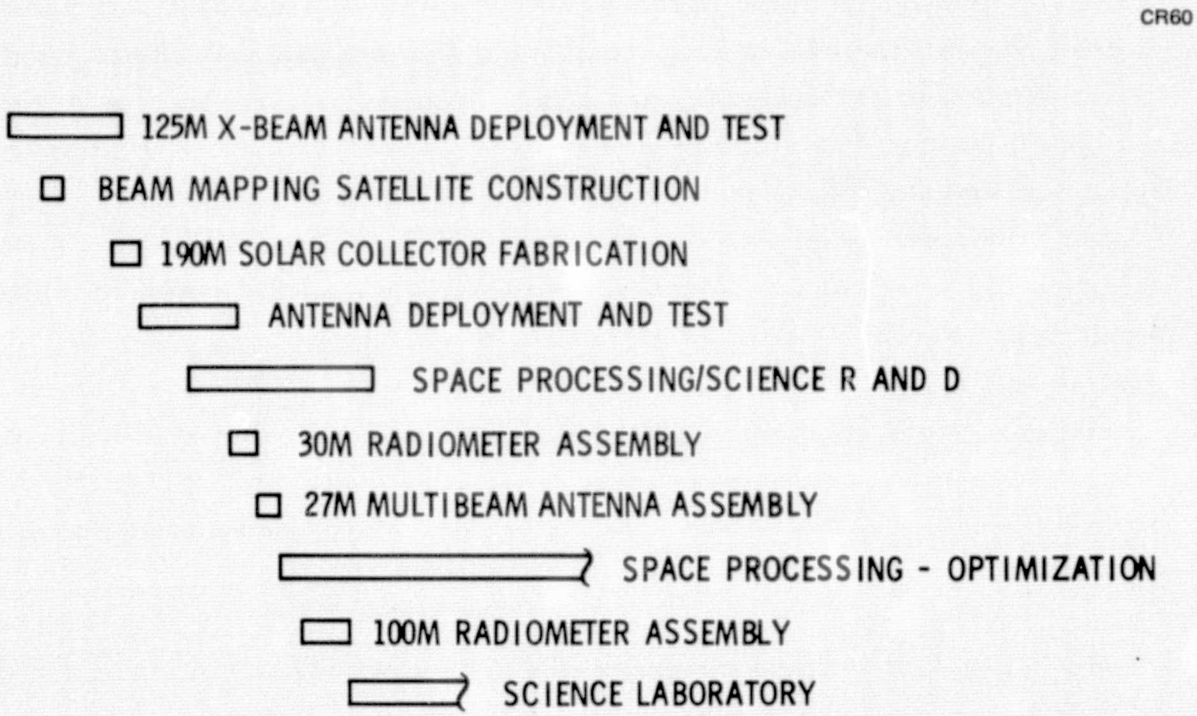

Figure 2-8. Accomplishment Sequence

Section 3
MISSION HARDWARE REQUIREMENTS

3.1 POWER PLATFORM SIZING

The power platform is a new concept introduced at the end of the Part 2 study. It is generally intended to be the Construction Base's primary power system, but is currently sized to meet early TA-2 microwave power transfer test requirements. However, it is designed for economy and not to meet all of the eventual TA-2 automated construction/productivity development objectives. Power platform sizing is primarily dependent on: 1) losses due to high voltage plasma leakage; 2) TA-2 antenna testing; and 3) the scope and timing of other objective elements (e.g., Space Processing), which are discussed below. A discussion of the Power Platform structural design and construction options is presented in Section 4.

3.1.1 High Voltage Plasma Leakage

In recent years, it has been increasingly recognized that the extra-orbital plasma environment can interact with spacecraft. Under some circumstances, such interactions can have serious results as in the spacecraft charging phenomena observed in synchronous orbit.

In low earth orbit, the relatively dense plasma can be attracted to high-voltage spacecraft surfaces in sufficient quantity to create significant leakage of electrical current. Results of early experimental work and analysis by NASA (at Lewis Laboratories and Boeing) indicated that, with solar cell arrays developing tens of kilovolts, leakage might exceed the arrays ability to supply current (Figure 3-1). Solar array oversizing is required to accommodate any plasma leakage that may exist.

For this reason, NASA/JSC convened a two-day working meeting of plasma specialists from government, academic institutions, and contractors to address the problem. It was this group's opinion that solar arrays in the 20 to 40 kV range may be practical at construction base operational altitudes

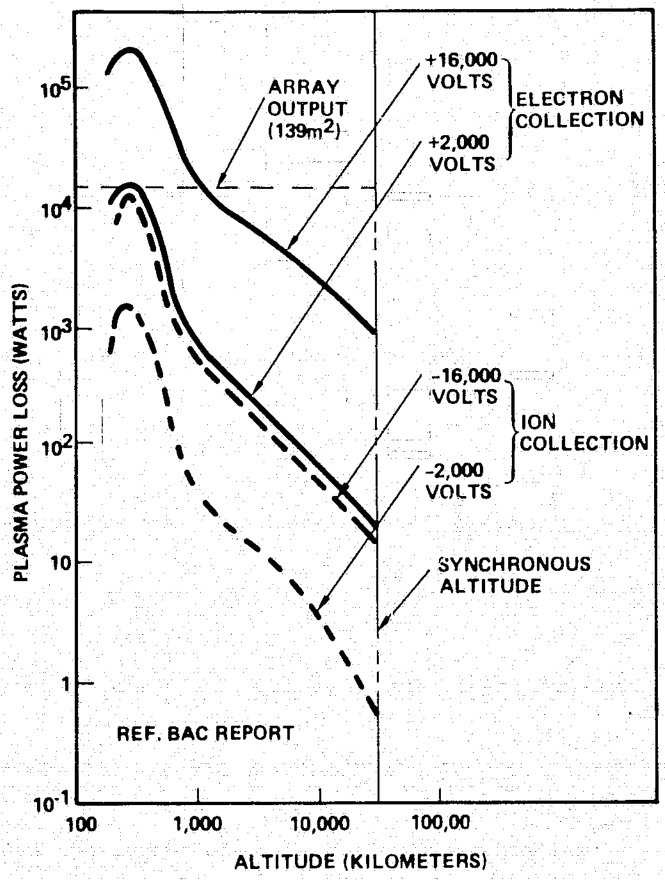

Figure 3-1. High Voltage Solar Array Plasma Leakage

(400 to 500 km) though insufficient work has been accomplished to guarantee this result.

This opinion resulted from several considerations. First of all, the operational altitude is some 100 to 200 km above the peak plasma density. Secondly, the problem of scaling from small experiments to large solar arrays involves the estimation of the plasma sheath (region of influence) dimensions. It was concluded that this dimension was large compared to the small-scale tests, but small compared to large solar arrays. This would effectively prevent the solar array developing the current flux per unit area observed in small scale tests.

As a first approximation, it was suggested that current flux could be estimated by assuming all plasma within a stream tube defined by the cross section area of the sheath normal to the velocity vector to be collected at the

array's velocity. This crude estimate gives answers about two orders of magnitude lower than the data of Figure 3-1 for an assumed sheath dimension of 10 meters. Hence, actual sheath dimension is most critical and it was the opinion of the conference attendees that the data of Figure 3-1 may overestimate the paramete r.

A third phenomena also enters as a mitigating factor. Equilibrium conditions on the solar array will be reached when equal numbers of positive and negative charges are collected per unit time. Hence, for a given voltage differential, voltage at the ends of the array will drift (with respect to the space plasma) until this condition is reached. Since electrons are more easily collected than ions, this means that the array will be predominately negative as indicated in Figure 3-2. Since, according to the data of Figure 3-1, negatively charged surfaces collect charges at an order of magnitude lower rate (than positive surfaces) this has a significant affect on total collection rate.

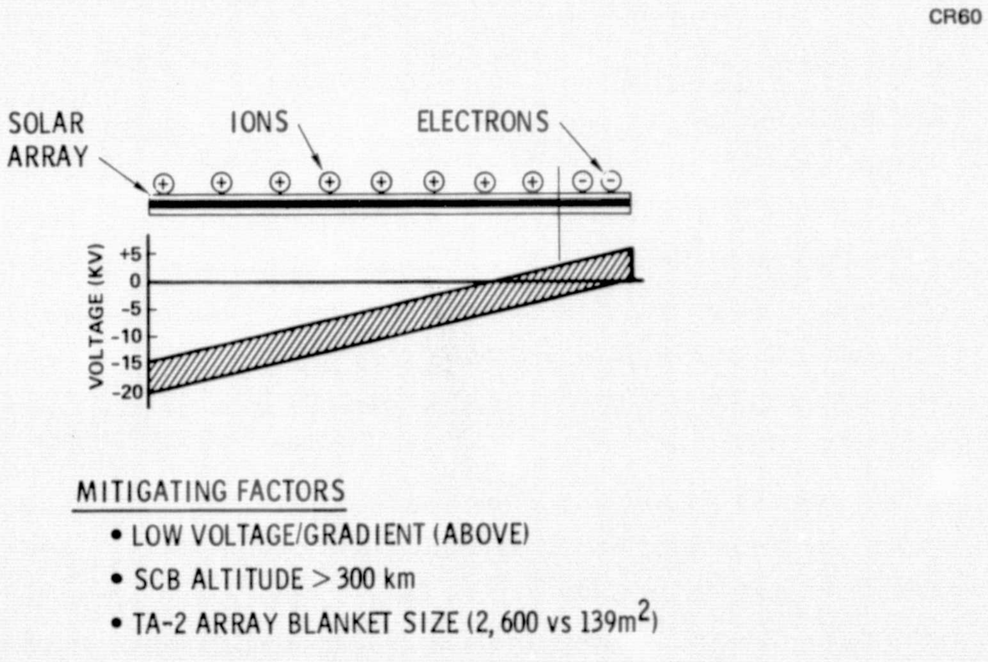

Figure 3-2. Voltage Distribution Across 20 kV Array

However, an additional phenomenon was identified that may have serious consequences for high-voltage antennas. A process similar to arcing has been repeatedly observed under conditions where an electrical arc is not expected because of very low gas densities. The conference concluded that insufficient evidence was available to determine if this phenomena would occur in free space or was a problem associated with the vacuum chamber walls.

While it is MDAC's conclusion that considerably more analytical and experimental work must be done before an irreversible commitment is made, a 20 to 40 kV array in low earth orbit (<400 km) is believed to be a reasonable SPS planning objective at this time. It should be noted that, in MPTS testing, a requirement for the 20 kV array can be avoided by use of a DC/DC boost regulator. This is the approach taken on the 250 kWe SCB power platform, which must be designed conservatively, although it leads to an incremental cost penalty of 5-10 million dollars. The MPTS antenna itself, because of its relatively small area, would not create a significant leakage in the absence of arcing. However, if the observed arcing can occur in LEO, MPTS tests may be forced to higher altitudes.

3.1.2 MPTS Testing

The electrical power requirements imposed on the power platform by the Microwave Power Transmission System (MPTS) testing, specifically the TA-2 antenna, are discussed in this section. The 9 x 14.4m TA-2 antenna is illustrated in Figure 3-3; the 15 subarrays are numbered for identification. The center subarray, Number 8, is higher power density than its neighbors. The dotted subarrays (e.g., Numbers 1A and 2A) represent a potential alternative configuration to be discussed subsequently.

Several candidate antenna power options are listed in Table 3-1. The differences are the result of either variations in number of amplitrons per subarray, or amplitron power level (e.g., maximum power or one-third of maximum power). The baseline at the conclusion of Part 2 of the study was Option 3A with 36 amplitrons in Subarray 8 and 4 each in the other 14 subarrays with all amplitrons operating at maximum power (typically 5.0 kWe added for each amplitron, except for 1 amplitron in each subarray at 6.25 kWe to start the cascade). The total RF power requirement was 479 kW_{RF}.

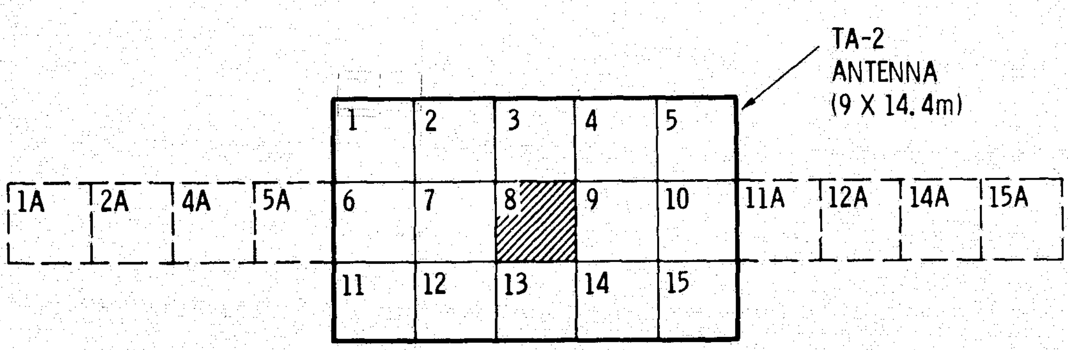

Figure 3-3. TA-2 Antenna Subarrays

The center subarray operated at the maximum attainable power density of ~20 kW_{RF}/m^2, which is representative of the center subarray of the operational SPS. The other 14 subarrays are one-ninth of maximum density ($1/9 \times 20 = 2.22\ kW_{RF}/m^2$), which approximates the peripheral SPS subarrays with a 10 db taper antenna.

The other schemes were investigated in Part 3 in order to reduce power requirements and cost of the expensive solar array power source. A combination of: (1) Option 3B (for maximum power density/thermal structural tests, using only Subarray 8 and its 8 contiguous neighbors, rather than 14 neighbors); and (2) Option 3C (for 15 subarray phase control tests—with Subarray 8 either switched, or reconfigured, to one-third of maximum power). The other options were rejected because they do not permit maximum power density tests.

Table 3-1

TA-2 ANTENNA POWER OPTIONS

Option • Subarray (Ident. No.)	Amplitron Quantity Per Subarray	 Total	RF Power, kW_{RF}	Total Electrical Power, kWe
Option 1				
• 8	2	2	6.25 + 5.0 = 11.25	
• 1-7 & 9-15	1	14	14 x 6.25 = 87.5	
Total		16	98.75	125.5
Option 2A				
• 8	4	4	6.25 + 3 x 5.0 = 21.25	
• 1-7 & 9-15	4	56	14 (6.25 + 3 x 5.0) = 297.5	
Total		60	318.75	405
Option 2B				
• 8	4	4		
• 1-7 & 9-15	4	56		
Total		60	1/3 x Option 2A = 106.25	135
Option 3A				
• 8	36	36	6.25 + 35 x 5.0 = 181.25	
• 1-7 & 9-15	4	56	14 (6.25 + 3 x 5.0) = 297.50	
Total		92	478.75	608.5
Option 3B				
• 8	36	36	6.25 + 35 x 5.0 = 181.25	
• 2-4, 7, 9, 12-14	4	32	8 (6.25 + 3 x 5.0) = 170.0	
Total		68	351.25	446
Option 3C				
• 8	36	36	1/3 (6.25 + 35 x 5.0) = 60.4	
• 1-7 & 9-15	4	56	14 (6.25 + 3 x 5.0) = 297.5	
Total		92	357.9	455

The resulting power requirement for TA-2 antenna testing is 358 kW_{RF}, the higher of the two options (3B and 3C) employed. The electrical power requirement is 455 kWe, based on the efficiency chain of Figure 3-4 and rated at the solar array blanket output. Mechanical alignment and phase control efficiencies are taken as unity, because the sizing criteria is based on radiated RF (i. e., kW_{RF}/m^2 power density) and not received RF.

The TA-2 antenna test requirements for duration and frequency are also of interest. To illustrate the type of development testing to be accomplished, Table 3-2 lists possible phase control performance test parameters. With the exception of fundamental circuit changes, the parametric variations are all aimed at verifying detailed subsystem requirements.

Typically, it is desirable to test combinations of parameters. Hence, the total possible number of tests and the total possible test time are large. However, a detailed review of TA-1 and TA-2 antenna test requirements

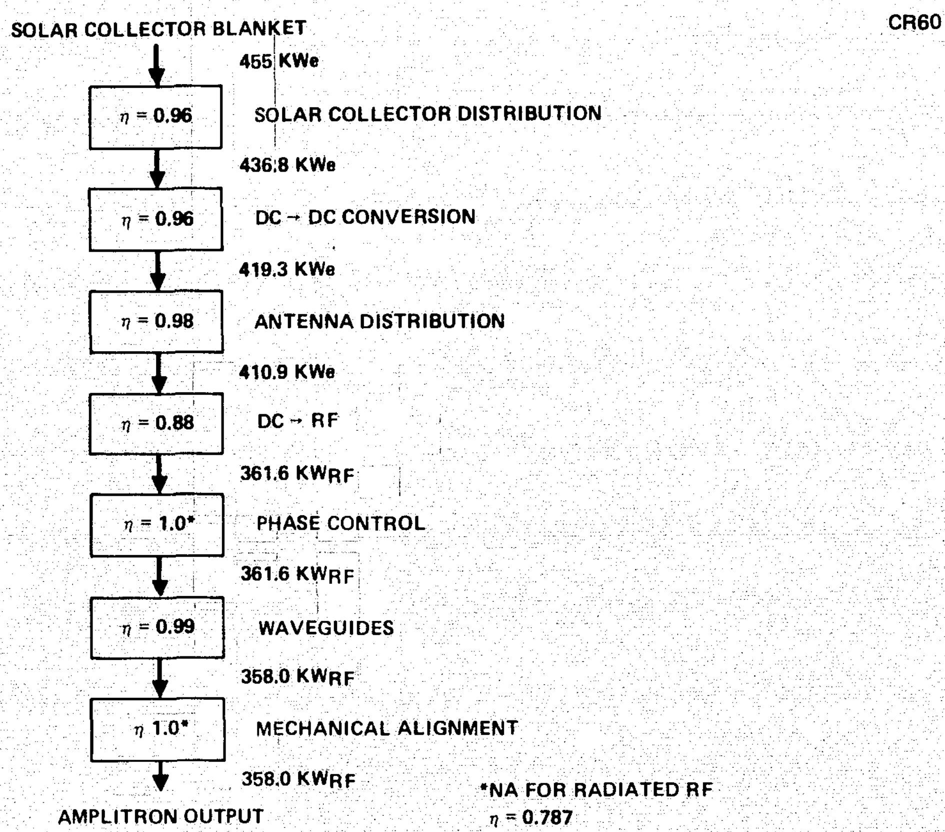

Figure 3-4. TA-2 Antenna Test Efficiency Chain

Table 3-2

MPTS TEST REQUIREMENTS—A POSSIBLE SET OF PARAMETRIC TESTS

Beam Pattern Maps	
Basic mapping:	10 error angles over 10 polar angles
Input voltage:	8 variations from nominal (4 (+) & 4 (-))
Input power:	8 variations from nominal (4 (+) & 4 (-))
Main beam frequency:	4 variations from nominal (2 (+) & 2 (-))
Pilot beam frequency:	4 variations from nominal (2 (+) & 2 (-))
Wave guide temperature:	2 variations from nominal (dark side tests)
Electronics temperature:	3 variations from nominal (box heaters)
Mechanical malalignments:	4
Fundamental circuit changes:	4

indicates that in either case, several hundred hours of antenna transmission would be adequate. Further, this is most appropriately accomplished on an intermittant rather than a continuous basis to permit data analysis, test plan and test hardware revisions Hence, a representative duration requirement is for testing of from a few minutes (as required for warmup and data taking) to perhaps one-half hour each orbit. This requirement is explored further in conjunction with power platform capabilities and sizing in Section 4.1.1.

A microwave configuration option that should be studied further is the dotted configuration presented earlier in Figure 3-3. The dotted configuration is formed by moving subarrays; for example subarray "1" is moved to the "1A" position. The dotted configuration provides: (1) a better beam steering test because of a larger number of phase control elements; and (2) better beam pattern gradients for easier measurement.

3.1.3 Other Objective Elements

A primary aspect of the study was to establish performance requirements upon which future space programs could be based. Accordingly, as the various missions were studied, emphasis was placed on determining what

support the SCB would have to provide. As an example, for construction it was determined that about 6 kW average power is needed to adequately light the construction scene during the dark side passages; this lighting is required from multiple angles to minimize eye fatigue associated with working in high contrast light. Some light also may be needed during the "day" to reduce the dark shadows. Power for fabricating beams also was considered. Composite beam construction requires high power to cure the plastic material with the requirement being directly proportional to the fabrication rate. An allocation of 2 kW was made for beam fabrication when done in parallel with EVA assembly operations; an additional 6 kW would be available to support automatic assembly machinery, or to increase fabrication rate if done at times when there are no EVA assembly operations. Analysis of crane operations (the crane requires about 250 watts per arm at maximum rate), EVA support, cherry picker operation, etc., required an average of an additional 2 kW resulting in a total of 10 kW average for construction during the 12 min. crew day.

The various objective elements were analyzed in a similar manner to establish their power requirements. In the area of space processing, equipment such as furnaces used in crystal growth have high power requirements while machinery for bioprocessing, such as separation devices, have relatively low requirements. Power requirements for all equipment items were derived and average (and short term peak) power requirements derived considering the timeline of associated activities. This was also done for the other objective elements as summarized in Table 3-3.

The SCB will be required to satisfy each objective element's power requirements. In addition, it will need 8 to 10 kW average, depending on the configuration, to support the crew and its own systems (e.g., communications). Further, in the Shuttle-tended mode, up to 21 kW average will be needed to support the Shuttle (13 kW) and a possible Spacelab module (approximately 4-8 kW).

From the discussion of Section 3.1.2, a major requirement for SCB power is the 455 kWe needed by the SPS TA-2 antenna test program. The cost effectiveness of building such a power supply, as opposed to one sized by

Table 3-3

SCB OBJECTIVE ELEMENT POWER REQUIREMENTS

Objective Element	Average Power kW	Short Term Peak Power kW
SPS		
TA-1	NA	75
TA-2	NA	455
Construction		
Lighting	6*	-
Fabrication	2*	9*
General Support	2*	-
Space Processing		
Crystals	12	18.5
Glass	20	30
Bioprocessing	4	8
Supporting Objectives		
Living and Working in Space	1	-
Multidisciplinary Laboratory	12	16
Sensor Development	10	12

*Required 12 hours per day

activities other than SPS, was investigated. Considerations were made as to what power levels might be desirable for support of other objectives; then these levels were assessed with respect to the SPS test program. As noted in Figure 3-5, the 455 kW power level is much greater than needed for any non-SPS program considered. Dropping this down to about 300 kW array (approximately 128 kW average) would provide a power level allowing all activities to be performed simultaneously and, by use of batteries, would allow about 26 minutes for full power testing per orbit for SPS TA-2 maximum standpoint. A power level of 250 kW (approximately 107 kW average) provides reasonable SPS test time at full power (18 minutes per orbit) and a good level for supporting various combinations of other activities. A power level of 150 kW (approximately 64 kW average) can support a reasonable program of space activities, but provides only about seven minutes per orbit of test time which is considered marginal.

3.1.4 Power Platform Selection

A number of other considerations were investigated in sizing the power platform. Cost, drag and attitude control considerations result in a desire

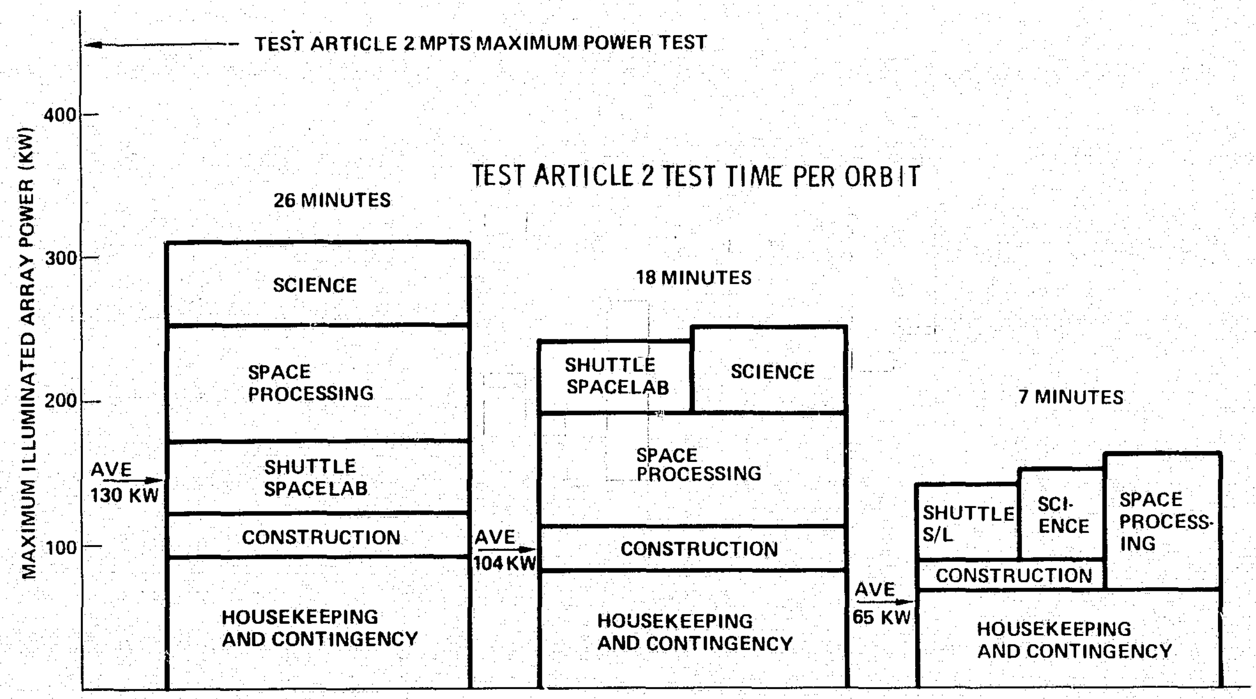

Figure 3-5. Large Power Platform Size Considerations

to make the platform as small as possible. Simplification of the orientation mechanism of the array tends to drive it bigger. Taking the above considerations all into account, a 250 kW level appears to be a reasonable compromise among the competing considerations and would provide a good margin for growth.

If the high power requirements associated with SPS and testing of TA-2 are deleted from power system sizing, then a smaller power module can be considered. Taking the requirements for the Construction Shack (or Shuttle in a Shuttle-tended mode), the requirements for various possible objective elements, and adding a contingency margin, a long-term program having a variety of possible combinations of activities can be supported by a power module having an average power output around 38 kW. A minimum level appears to be about 25 kW. At this level, all activities can be supported to some degree though generally only one at a time. A 38 kWe Power Module was selected.

3.2 MICROWAVE POWER TRANSMISSION

Critical to realization of a practical and economical SPS is the ability to efficiently and accurately concentrate and direct microwave power to a selected point on earth while suppressing high power radiation to other ground locations. While this is clearly feasible, practical development of an array antenna of such order of magnitude improvements in size and accuracy has historically always involved extensive development testing of prototype components. Typically, tests over a wide range of parameters can be economically justified since knowledge of component performance in the actual operating environment eliminates the need for expensive "over-design" to assure performance in areas of uncertainty.

Important factors in the cost, weight and complexity of the large scale microwave power transmission system required for SPS are: (1) the maximum spacing between pilot pulse phase control sensors; (2) the maximum size of individually phase controlled subarrays; and (3) the degree of commonality allowable in subarray components being utilized in different sectors of the large array antenna.

The above hardware considerations are discussed in the Appendix. The resulting limitations are highly dependent upon mechanical steering accuracy, mechanical deformity, frequency stability, and environmental effects on subarray radiation. Accurate validation of these effects in space will permit an optimum cost-effective design to be implemented.

Tentative evaluation, without empirical data from space, indicates: (1) a 10-meter spacing between pilot pulse sensors; (2) a 3-meter-square, phase-controlled sub-array; and (3) multiple subarray designs for operation in different power-density areas.

Ground development testing of phased array antenna systems of this size to the required accuracy is believed to be impractical at best and probably impossible within current technology and facilities. In this case, determination of performance involves measurement of antenna beam patterns, including grating lobes, to an accuracy that cannot be achieved under conventional antenna range tests because of reflections from ground and other nearby

objects, atmospheric refraction associated with range distances of four to hundreds of kilometers, and operating the microwave components in a vacuum controlled environment without affecting the radiation patterns.

Space must then be used as the antenna range for all development tests involving large arrays and prototype amplifiers. This results in a requirement for long duration manned space flights, which would be most economically undertaken with use of a permanent habitation on orbit instead of repeated use of short duration Orbiter sortie missions.

A typical high-gain antenna beam pattern (including some side lobes) is illustrated in Figure 3-6. In the usual parabolic dish antenna, accuracy of the beam formation is largely a function of dish geometric accuracy. In a phased array, as in MPTS, it is primarily a function of phase control and geometric accuracy. Hence, measuring the beam pattern is the fundamental technique for determining both electronic and mechanical performance.

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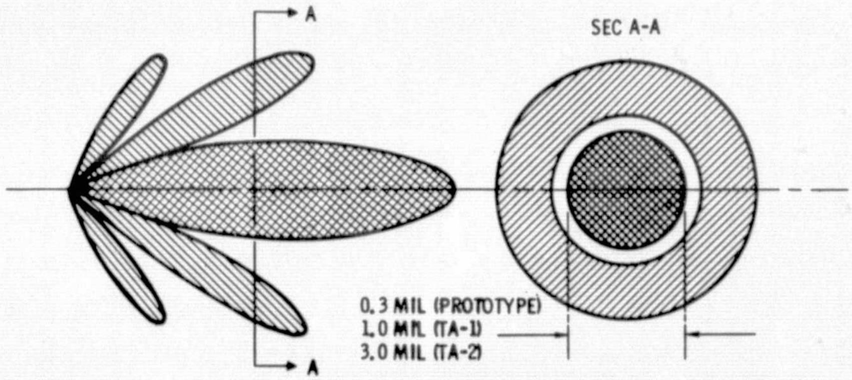

	CURRENT RADAR	SPS REQUIREMENT	TA-2	TA-1
STEERING ACCURACY	1 MIL	0.005 MIL	0.3 MIL	0.1 MIL
BEAM ACCURACY	"SEVERAL MILS"	0.005 MIL	0.3 MIL	0.1 MIL

Figure 3-6. MPTS Antenna Patterns

In reviewing performance of current phased array radars, it must be recalled that data smoothing and calibration techniques allow tracking accuracy to be approximately an order of magnitude better than beam formation or steering accuracy. In MPTS, however, such errors result in either (or both) RFI problems from increased side lobes or larger rectenna requirements resulting from a distorted main beam. The main lobe accuracy requirements for the prototype MPTS are computed on the basis of a random error that results in an additional 1.5 square miles of land required at the rectenna site. To demonstrate prototype quality of phase control performance, test article performance must be as indicated. But to insure that such performance has been achieved, beam pattern measurement accuracy should be about one order of magnitude better—i.e., the main lobe of TA-1 should be measured to an angulation accuracy of approximately 8 seconds (0.03 milliradians).

Previous discussion has involved the rise of a boresighted camera for measuring angular variations; an alternative that should be studied in the future is the use of a laser radar for these measurements.

3.3 SPACE PROCESSING REQUIREMENTS

The objective of Commercial Space Processing is an outgrowth of increased scientific understanding and technological applications of materials-processing-related phenomena in space. Three particular advantages of space which directly influence Space Processing include (1) the reduced gravity environment which eliminates gravity driven phenomena such as thermal convection, (2) the access to essentially unlimited volumes of high vacuum and (3) the direct access to the entire spectrum of solar radiant power. There are three generic types of processes which take direct advantage of the space environment: (1) containerless processes where the material being worked is not in contact with walls of the furnace, (2) conventionless processes where gravity-driven forces do not disturb a liquid material being worked and (3) sedimentationless processing where a multiphase material does not separate either by Stokes flow or by component settling to the bottom of the container.

The research phase of Space Processing will pursue basic investigations which seek in-depth understanding of the physical phenomena which affect materials processing in space. The commercialization phase includes activities required to demonstrate the economic as well as technological feasibility of Space Processing. This phase requires a spaceflight demonstration project to (1) develop processing capabilities which are suitable for commercial production, (2) evaluate and optimize optimize proprietary production process parameters, equipment and procedures, (3) determine that the characteristics and properties of the materials produced are suitable for the intended final product and (4) evaluate and refine equipment maintenance and servicing procedures to support full-scale commercial production.

In order to initiate the spaceflight demonstration project a Space Processing Development Facility is required. The functional requirements of this facility, which as described above must be suitable for the evaluation of processing procedures and equipment for eventual transition to commercial production, are as follows:

- Support of manned test projects with one to two crews for up to 90 days.
- Accommodation of bio-materials processing and containerless processing of ultrapure materials and shaped crystals.
- Analytic and materials characterization capability for in-process and final products.
- Provision of environmental isolation for contamination critical and toxic materials.
- Availability of 8 to 15 kW bus power and related heat rejection.
- Capability for maintenance, modification and changeout of equipment on orbit.

The tests which need to be conducted in this facility must be fully supported by trained personnel in space for durations from 30 to 90 days. While only modest size crews will suffice (one to two persons), the onboard activities will involve operating the processors and analyzing the product in a systematic manner. The equipment accommodated by the facility must permit evaluation of biologicals and inorganic materials. Certain materials will

be contamination-sensitive, and isolation of the processing apparatus will be required. The electrical power and equivalent heat rejection requirements will range from 8 to 15 kilowatts. The initial equipment installed in the facility will be derived from Spacelab-type payloads and equipment racks, such as those items that will be developed within the Space Processing Activity (SPA) program. As the testing program matures, other equipment items with advanced capabilities will replace the initial units thereby necessitating an equipment changeout capability. Some level of equipment maintenance will be required to ensure the continuing availability of the facility.

3.4 100-METER RADIOMETER

The requirement for a radiometer antenna system with a diameter of 100 meters stems from an Outlook for Space requirement to provide earth resources data with a resolution of 1 Km at an altitude of 800 Km. As shown in Figure 3-7, frequencies were assigned to certain antenna sizes in order of produce the requisite resolution. However, this data was derived assuming an antenna type known as a paraboloid of revolution using 100% of the

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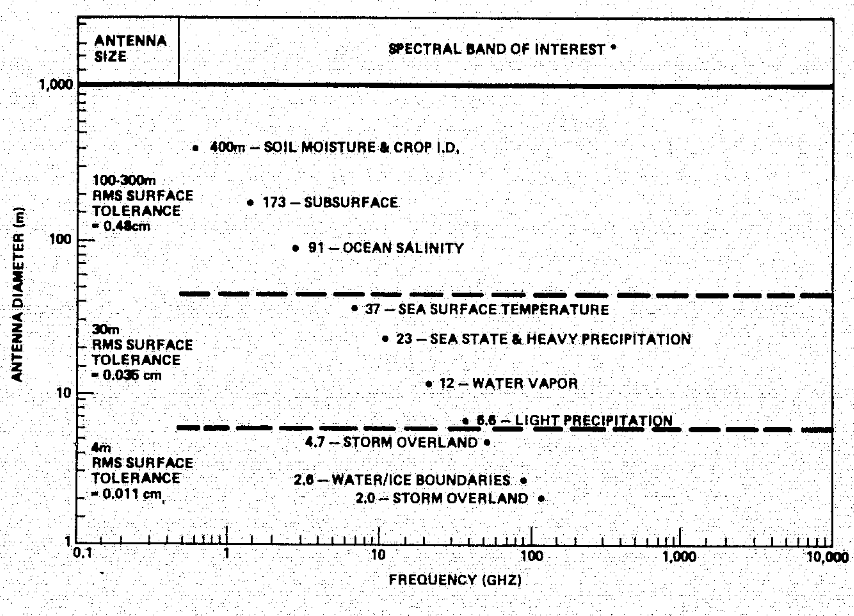

Figure 3-7. Allocation of Spectral Bands to Antennas (800 km Orbit, 1.0 km Resolution)

effective aperture. In order to provide a scanning capability, the antenna type selected is a parabolic torus with an effective aperture of 50%. As a result, sea surface temperature, sea state and heavy precipitation at frequencies of 10.7 and 6.66 GHz were actually assigned to this antenna.

The reason for selection of the parabolic torus rather than the parabola of revolution for a scanning radiometer is illustrated in Figure 3-8. The parabolic antenna focuses parallel incoming rays at a point on the axis determined by the focal length to diameter ratio of the antenna surface. For small antenna diameters the entire dish may be rotated to perform a scanning operation and excellent performance results. However, as antenna diameters grow to 100 or 300m, their movement becomes impractical due to the large moments of inertia involved and the lack of a fixed platform to react against.

It is, of course, possible to move the feeds in a locus either side of the axis and obtain scanning. However an aberration termed "coma" results

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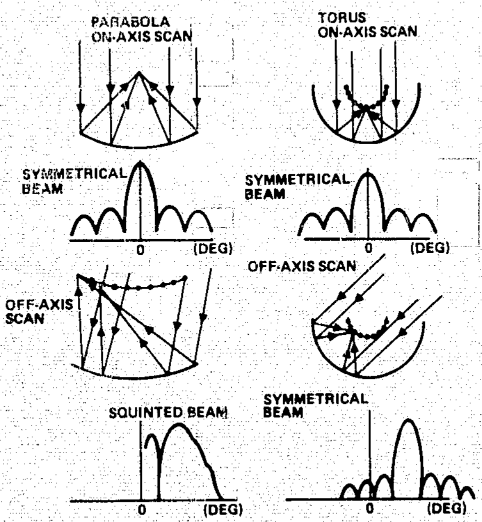

PARABOLIC ANTENNA CHARACTERISTICS
- 100% OF APERTURE USED
- SCAN LIMITED TO $\simeq \pm 10^{\circ}$
- VARIABLE FOCAL LENGTH
- SYMMETRIC—AMENABLE TO DEPLOYMENT

180° PARABOLIC TORUS ANTENNA CHARACTERISTICS
- 50% OF APERTURE USED
- SCAN LIMITED TO $\pm 60^{\circ}$
- FOCAL LENGTH = R/2
- UNSYMMETRIC—DIFFICULT TO DEPLOY

Figure 3-8. Parabola Versus Parabolic Torus

which produces an unsymmetrical pattern shape, the sidelobes being higher on the boresight side of the main beam than on the other side. This is illustrated in the figure by noting the change in focal point with parallel rays arriving at an angle. Also shown is the ability of the spherical surface to still focus rays arriving at an angle to a single point. One of the penalties involved in its use over wide scan angles is that only 50% of the aperture may be instantaneously employed for 120° scanning. However, this figure may be increased for lesser scan angles.

Electronic rather than mechanical scanning was selected after an antenna scaling analysis (see Table 3-4). This showed that "G" levels at the edge of the wheel supporting the feed horns and elliptical secondary reflector of the original Gregorian design (secondary reflector located on the opposite side of the focal point from the primary reflector) were unacceptable. This resulted in the elimination of the secondary reflectors and the installation of feedhorn sets at a radius of 50m from the face of the radiometer and located over a 120° arc. The secondary reflectors were eliminated although useful for the correction of aberrations whenever antenna diameters exceed wavelengths on the order of 100 times.

The construction of the antenna is shown in Figure 3-9. It is composed of a frame of graphite polyimide tubing and covered with a wire mesh to provide the reflector surface. The mesh has a very thin gold coating a few microns thick to provide low thermal absorption and emission. The other surface is coated with a paint providing similar characteristics to prevent warping of the surface.

Table 3-4

TRADE-OFF MATRIX ANTENNA SCALING-MECHANICAL SCAN

Parameter	Antenna Size				Comments
Diameter (m)	4	30	100	300	None
Beamwidth (deg) (at 53 GHz)	0.2	0.03	0.01	0.0027	
Resolution (km) (at 53 GHz)	1.2	0.18	0.06	0.02	None
Focal Length (m)	1.0	7.5	25.0	75.0	None
RMS Deviation (cm) (at 1 dB Gain Loss)	0.03	0.03	0.03	0.03	Panels may be formed to 0.01 cm (0.003-in.)
G-Level Wheel Edge (at 400 rpm)*	182.5	1,369	4,564**	13,692**	G-Level Unacceptable at 100, 300m
Feed Requirement rpm Maintained at 400*	1	8	20**	60**	Quantity of Feeds Unacceptable at 100, 300m
Stability (deg) (at 10% Beam Width)	±0.01	±0.0015	±0.0005	±0.00014**	Stability Requirement For Beam Beyond State of Art

*Optional Approaches

**Unacceptable

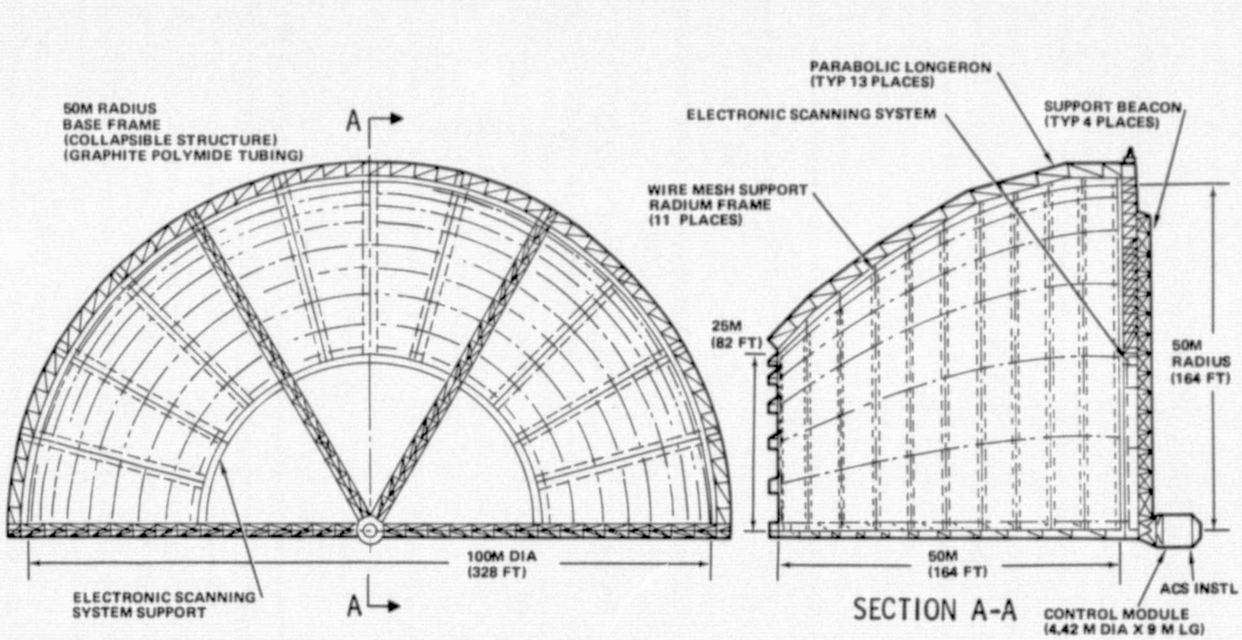

Figure 3-9. Electronically Scanned 100m Parabolic Torus Radiometer

Section 4

MISSION HARDWARE DESIGN AND CONSTRUCTION

4.1 POWER PLATFORMS

Parametric solar collector designs examined in Part 3 of the SSSAS have ranged from 89 kWe (Power Module, 38 kWe average at the bus) to 500 kWe in size. The power platform solar array selected for the SCB program provides 250 kWe beginning of life (BOL) when oriented normal to the solar vector. It is a nonconcentrating system based on SEP solar cell blanket technology.

From review of the Part 3 effort it is apparent that, as in most aerospace vehicle design, a primary structural design problem involves the physical interface with other subsystems. In the case of solar collectors this primarily involves the attachment of solar cell blankets and perhaps plastic reflectors. It is obvious that considerable detailed design and test of various attachment schemes needs to be done before adoption of a specific scheme. Such processes may, in fact, dictate selected structural configurations.

A similar problem exists in attachment of structural members to each other. Here the opportunity exists for considerable innovative design. Since loads on orbital structure are small, joint efficiency can be sacrificed for construction simplicity without significant penalty. While welding of joints in space is certainly feasible, and welding is most efficient, quality control of welds has historically been a difficult problem. This fact and the small penalty that is associated with inefficient joints tend to favor simple mechanical joining methods such as crimping.

4.1.1 Power Platform System Analysis and Design

A summary of the characteristics of the selected 250-kWe power platform system is presented in Table 4-1, and the weight in Table 4-2. The power platform system illustrated in Figure 4-1 basically consists of: 1) the 250-kWe BOL solar array; 2) a 169-kW-hr capacity NiCd Battery, at

Table 4-1

POWER PLATFORM SYSTEM CHARACTERISTICS

System Bus Voltages, VDC	26, 76 & 112
Solar Array Output, BOL/EOL, kWe	
• Solar Oriented(1)	250/~200
• Typical(2)	225/ 180
System Average Output (Array Capability, BOL/EOL), kWe	
• Solar Oriented Array(1)	106.6/~85.3
• Typical(2)	96.0/~76.8
System Average Output (Battery Capability),(3) kWe	40
Array Blanket Area, M^2	2,579
Blanket Concept	SEP Technology; 8m wide rolls
Array Orientation	Quasi-Solar(4); 1-Axis Gimbal • X-POP at Low β • X-Vertical at High β
NiCd Battery Life, Years	2.5
Battery Capability (100% DOD), kWH	169
Battery DOD, %	~15
Radiator Area, M^2	108

(1) Normal to Solar Vector (e.g., when $\beta = 0$)
(2) Typical Through β Cycle
(3) Initial battery complement at ~15% DOD, BOL & EOL
(4) X is Solar Array principal axis

Note: End of Life (EOL) is 10 years

100-percent depth of discharge (DOD); 3) power conditioning equipment; 4) power system radiator; 5) a berthing port; and 6) a one-axis, ±180 degree gimbal system.

The 26V output is for the existing Shuttle and other low-voltage equipment. The 112V output is for new equipment (e.g., space processing) that is yet to be designed. These are regulated, whereas the 76V output is unregulated (76V-118V), primarily for conversion to 20 kV at the TA-2 antenna.

Table 4-2

POWER PLATFORM WEIGHT

Item		Weight (kg)
Solar Array Blanket		2,579
Structure and Miscellaneous		3,943
• Array Structure	(1,720)	
• Assembly Fixture/Radiator/Thermal Control	(1,134)	
• Attachments	(515)	
• Bus/Wire	(232)	
• Gimbal and Berthing	(342)	
Batteries		6,240
Power Conditioning and Miscellaneous		1,045
• Battery Chargers	(109)	
• Load Regulators	(604)	
• Wire	(232)	
• Attachments/Miscellaneous	(100)	
		13,807 kg

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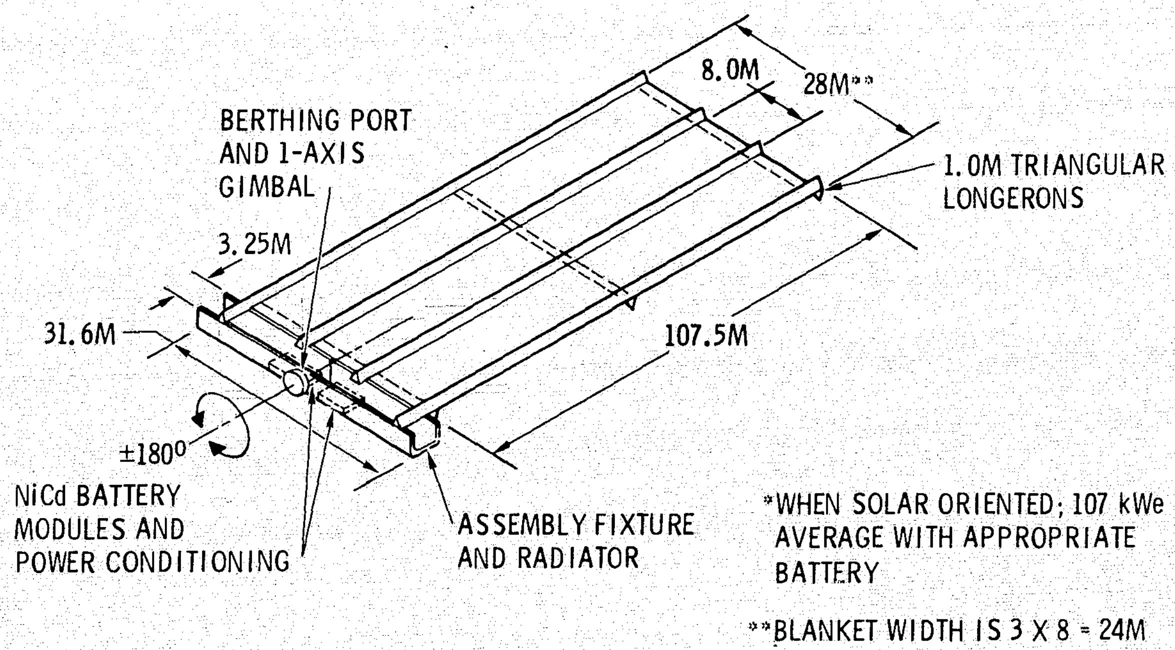

Figure 4-1. Power Platform System-Ladder Concept (250 kWe Array, Bol)*

The solar array output varies with β throughout the year, as discussed in Appendix 3. The typical value noted was selected to be 0.9 times the maximum value (at $\beta = 0$); 0.9 is probably conservative. The system is rated at BOL, because the most severe requirement, TA-2 testing, occurs early in the program. The 250-kWe BOL array has the capability of providing 106.6 kWe average at the load bus; however, the initial battery complement was selected consistent with a 40-kWe average load and 15-percent DOD. This represents the initial extension of the 38-kWe power module capability; additional batteries and power conditioning are added as required: 1) a separate deep-discharge battery dedicated to TA-2 testing; and 2) up to 66.6-kWe average capability (66.6 + 40 = 106.6 kWe average) for growth of average loads to the array energy capability.

The radiator is required to provide precise temperature control of the power conditioning equipment and NiCd batteries as required for long life and high performance; it is integrated into the assembly fixture structure. The batteries and power conditioning equipment are located on the bottom side of the assembly fixture as noted in Figure 4-1. This location provides easy access for maintenance and replacement using the crane, and acceptable lateral CG control in the Shuttle launch configuration.

The solar array blanket rolls are 8m wide and 108m long, attached to the composite material, triangular longerons. The solar cell blankets are based on Solar Electrical Propulsion System (SEP) technology, but with a higher packing factor, because of the continuous nature of the blanket, as contrasted to the SEP hinge arrangement.

The selection of 250 kWe for the power platform array output is based on the ability to meet the requirements for: 1) TA-2 testing as outlined in Section 3.1.2, and 2) other missions described in Section 3.1.3. The total TA-2 elapsed test time has been plotted as a function of available solar array size (Figure 4-2), based on solar array/battery system peak load characteristics and a realistic estimate of the minimum necessary parametric antenna tests. The time required to take a single beam pattern is a strong function of antenna angular accelerations, which must be low since deformations of both the antenna structure and the electronic components must be minimized. Also, since the test time available below an array power of 200 kWe approaches the estimated warmup time, total elapsed test duration in this region is uncertain.

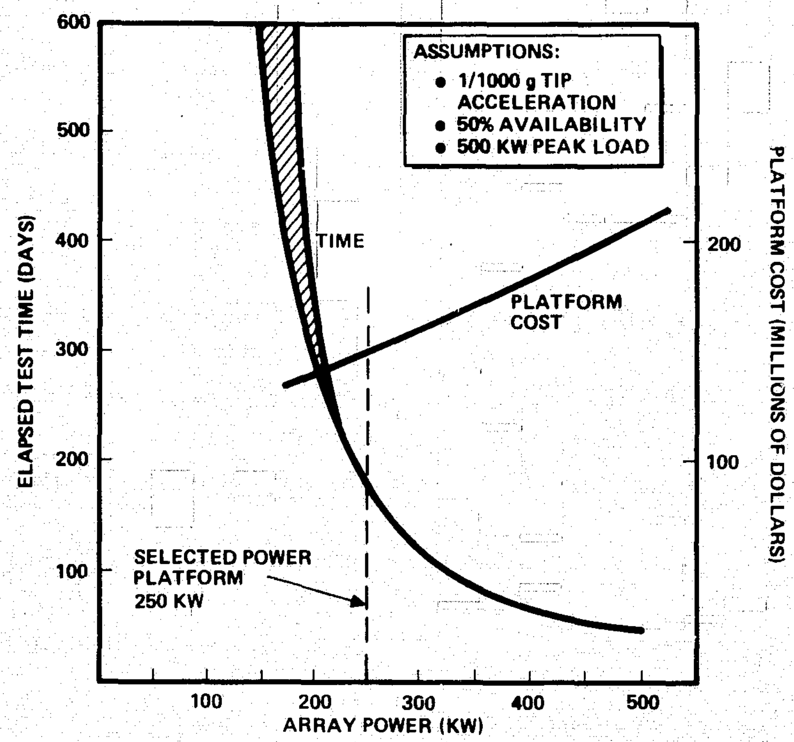

Figure 4-2. MPTS Antenna TA-2 Test Requirements

At the other end of the scale, if a 500 kWe array is available, total elapsed test duration is quite short and the assumed 50% availability figure is questionable. For these reasons a 250 kWe (maximum illuminated power) array has been selected as a suitable compromise between the conflicting desires to minimize both operating cost (elapsed test time) and initial platform cost.

4.1.2 Deployable Configurations

Configurations which involve the least development effort to make the first article operational generally utilize a structure which is manufactured on the ground and deployed on orbit. Two concepts are presented here. The first, a replica of Test Article 2 solar collector geometry, uses deployment plus orbital assembly. A "square rigger" solar collector arrangement, which suspends two solar cell blankets between spars on a central mast, is a totally deployed configuration with no orbital assembly required.

4.1.2.1 Deployable TA-2 Concept

This concept resembles the fabrication and assembly TA-2 configuration

presented in Part 1 and Part 2 but has a completely different structural concept, Figures 4-3 and 4-4. It consists basically of a series of 15 panel frame packages. Panels are hinged to unfold accordian-fashion and when, attached to transverse beams, have essentially the cross-sectional shape as the TA-2 solar collector detailed in Part 2. The individual frames are 3.33 meters wide and nearly 18 meters long. Some frames have solar cell blankets in them and the rest have reflector material in them. After each

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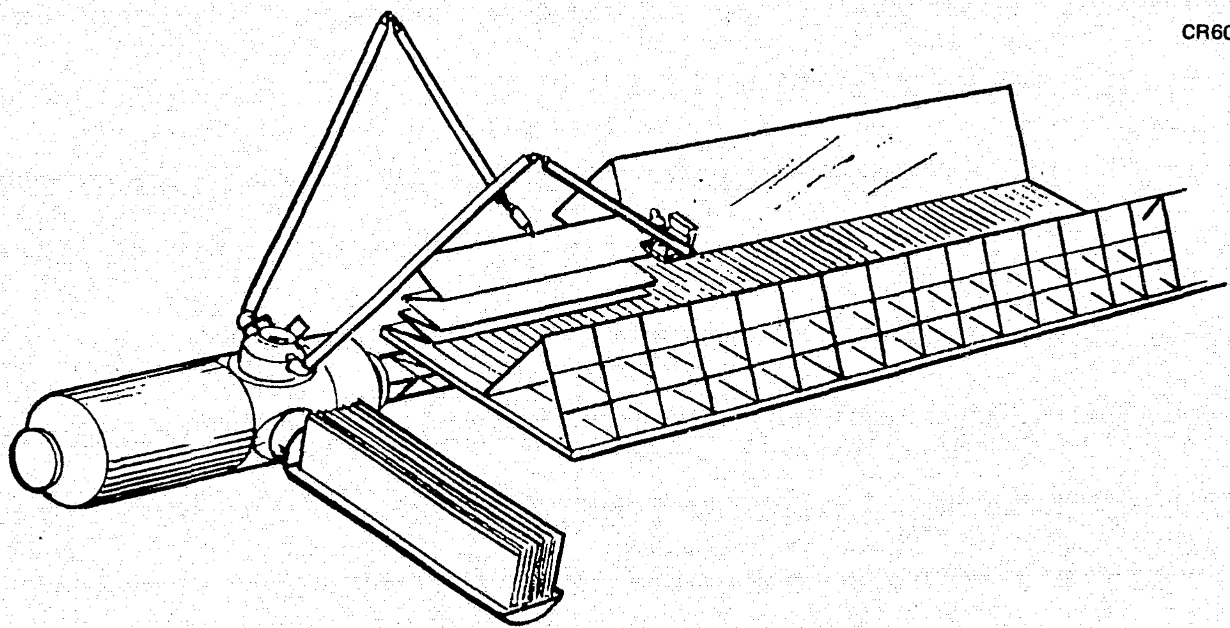

Figure 4-3. 456-kW Power Platform Deployment and Assembly

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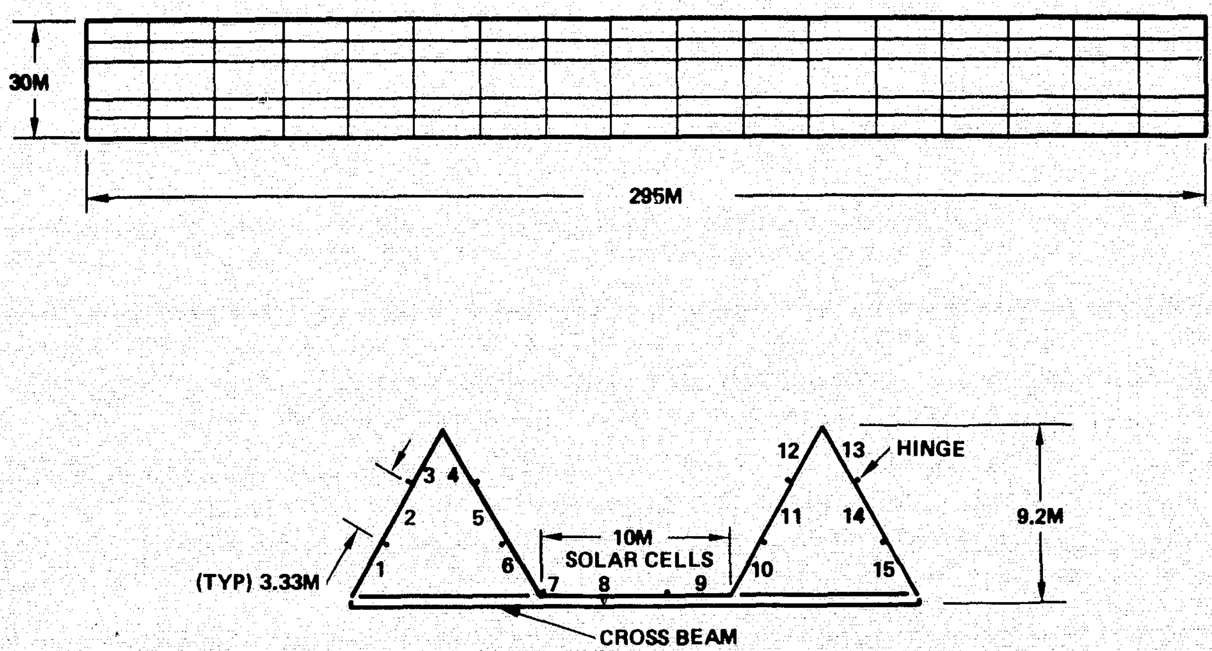

Figure 4-4. Deployable 456-kW Power Platform (Trail Configuration)

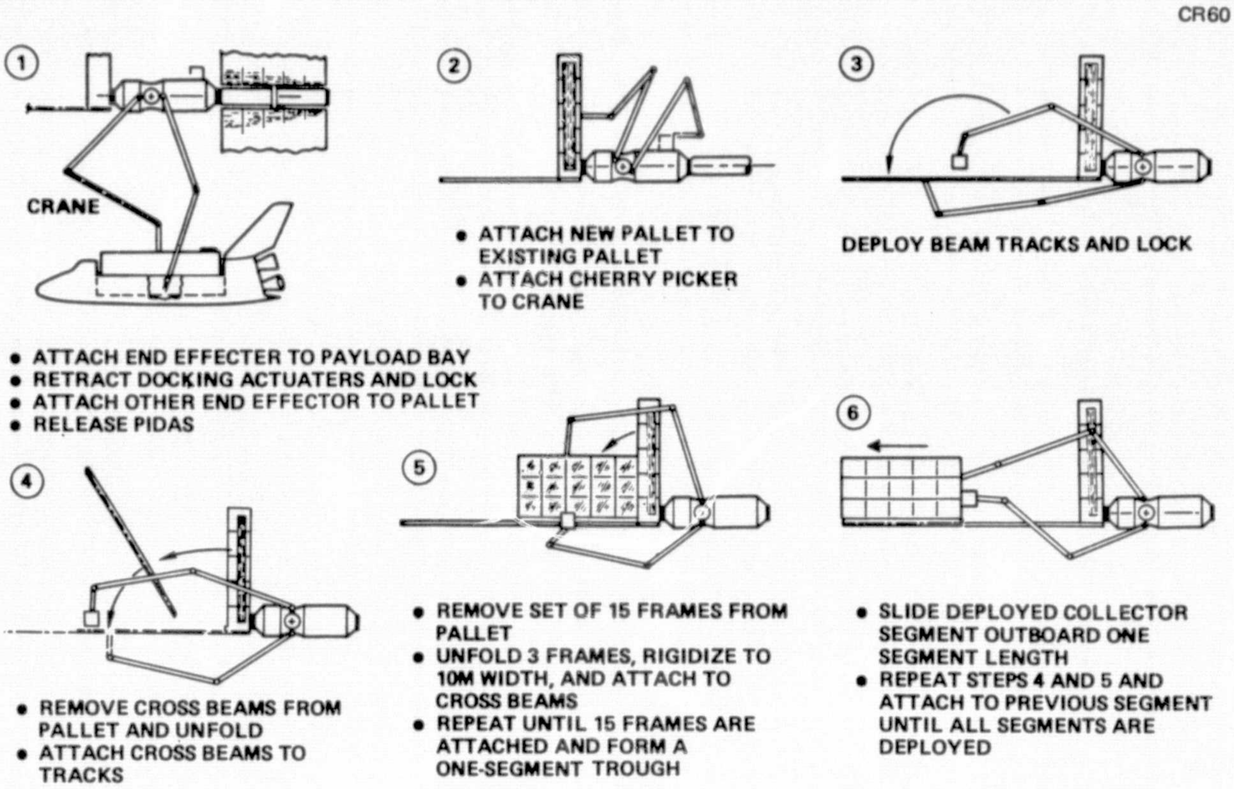

Figure 4-5. Deployable Power Platform Deployment Sequence

full-width 15-panel section of array has been deployed it is moved along a holding fixture to allow the next set of frames to be deployed, and joined to the first. The sequence of deployment steps is illustrated in Figure 4-5.

4.1.2.2 Square Rig Deployable Concept

This concept is totally deployable with no assembly involved as occurs in the above concept. It consists of two solar cell blankets suspended between spars which are mounted at each end of a central telescoping mast (see Figure 4-6). Figure 4-7 shows the collector folded and collapsed for transport stowage in the Orbiter. The central mast is a telescoping square tube structure with a docking system interface on the outer mast element. The other end of the mast (the innermost mast element) has a structure to which the outer spars attach when they are deployed laterally to the mast. The inner spars with the solar folded cell blanket are hinge-mounted on the outer end of the external mast element, providing 13.72 m (45 ft) separation between the docking interface and the inner edge of the array when deployed.

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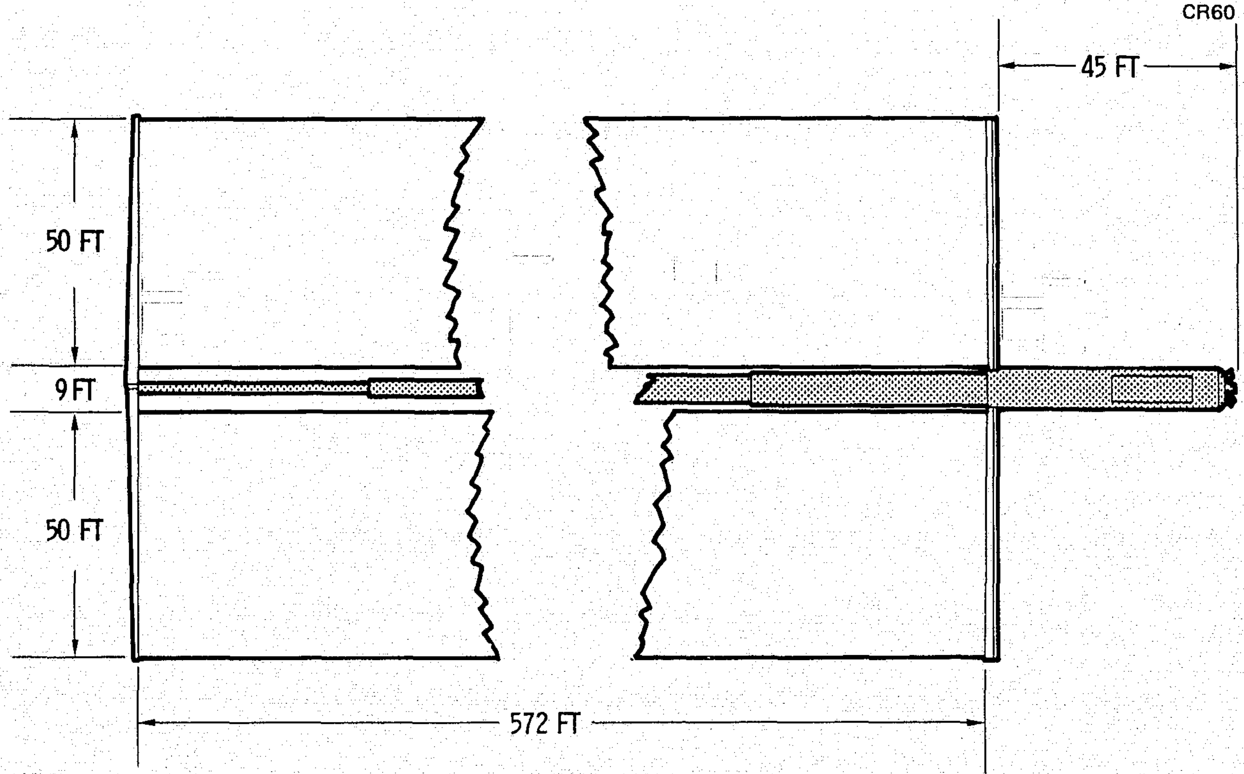

Figure 4-6. 500-kW Deployable Power Platform

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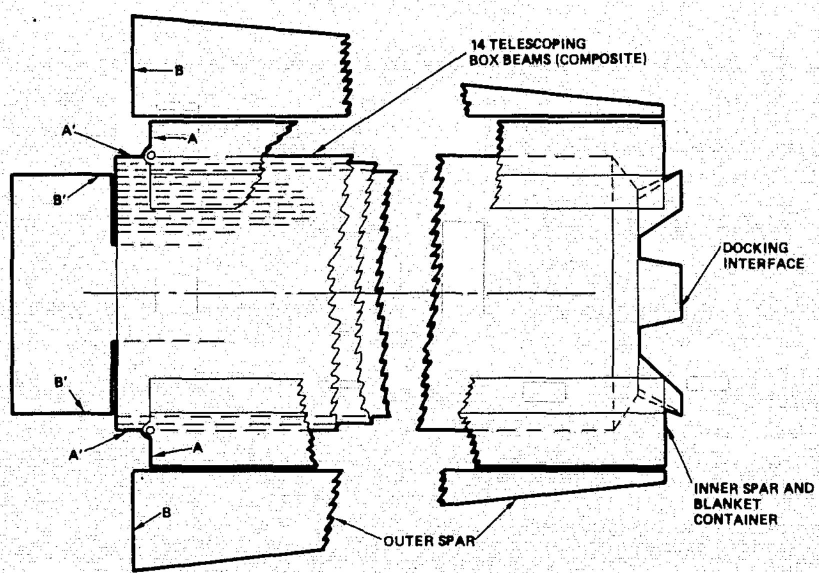

Figure 4-7. 500-kW Deployable Power Platform with Collector Collapsed for Transport

With the spar system deployed and the solar cell blankets attached, the mast is extended via a cable-pulley system, (Figure 4-8) until fully deployed.

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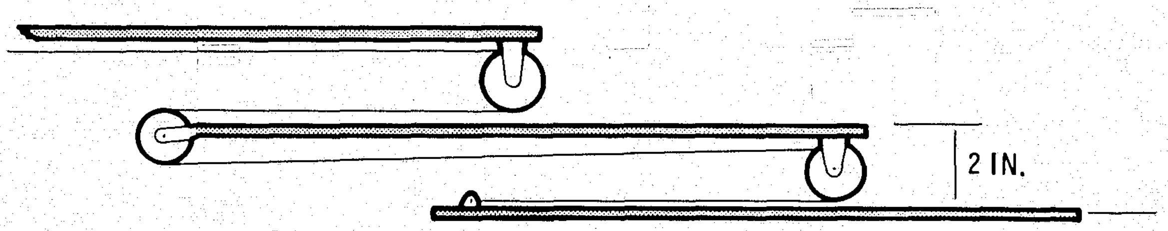

3/32-IN. CABLE

MIN BREAKING LOAD = 920 LB
X 4
3680 LB

BLANKET TENSION = 5 LB/FT x 100 FT = 500 LB

MINIMUM PULLEY OD = 1.75 IN.

REDUNDANT MOTORS ON DUAL POSITRACTION-TYPE DIFFERENTIAL DRIVE – HAND WINCH BACKUP

Figure 4-8. Cable Extension System

The telescoping mast consists of 14 sections, square in cross section, which are made of composite materials. Figures 4-9 and 4-10 illustrate the construction concept of the elements. They utilize an open diagonal network of tows wound in a double helix, rather than weaved, to minimize the bending distortion of the tow elements as occurs in an over and under weave. The open-lattice box structure has a longitudinal tow encompassing the entire corner area both internally and externally to sandwich the lattice in the corner. In fabrication, the square cross section has a distinct advantage since a single expanding mandrel can be used to mold all 14 telescoping sections. The mast elements use end frames which may be either aluminum or composite material and which are fabricated as shown. The end frames mount the pulleys used in the deployment system.

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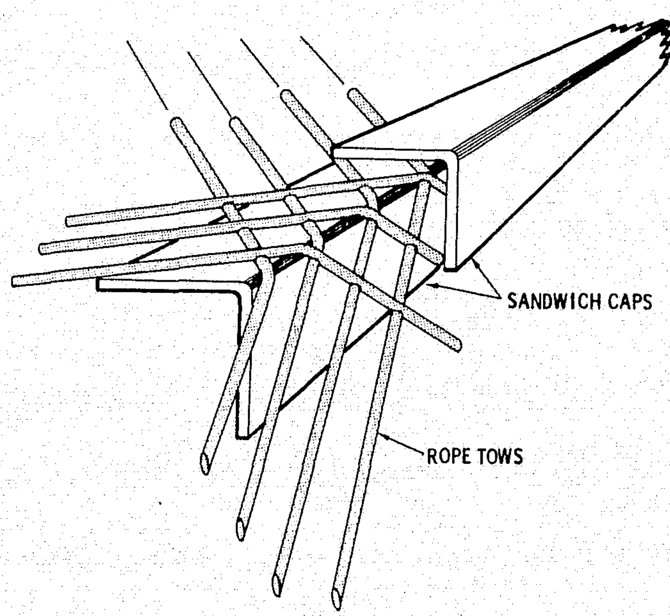

Figure 4-9. **Square Composite Beam Concept**

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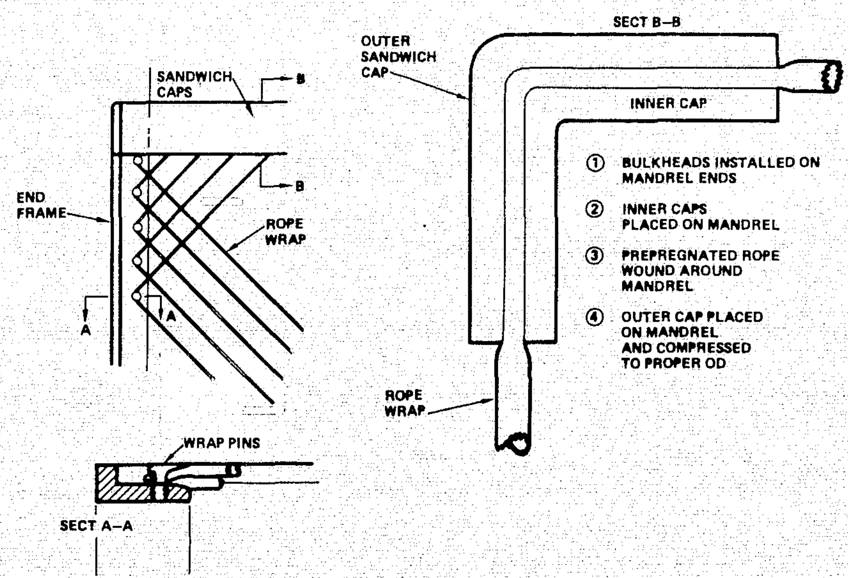

Figure 4-10. Square Composite Beam Concept

4.1.3 Assembled Configurations

A large power platform (500 kW to 1 MW or more), assembled in space from elements fabricated on the ground, can be packaged in a volume that is a very small percentage of the cargo bay volume by storing the structural truss members inside nested mirror and blanket rolls. A 456-kW power platform designed for space assembly and this method of launch packaging is shown in Figure 4-11. As illustrated, the solar collector configuration is similar to that illustrated in 4-6, with two solar blankets suspended between spars supported by a central mast. The bending and torsional stiffness of the assembled array is provided by a center beam with three longerons located at the corners of a 10m equilateral triangle. The 10m-wide solar cell blankets are attached at one end cross beam with negator springs which hold the blankets under a constant tension load of 58.4 newtons per meter (4 lbs per ft). The blankets are not attached along the sides, which are held straight by tension in the edge conductor straps. This method of mounting the blankets eliminates cyclic thermal stresses from the large temperature excursions experienced by the blanket as it passes in and out of the Earth's

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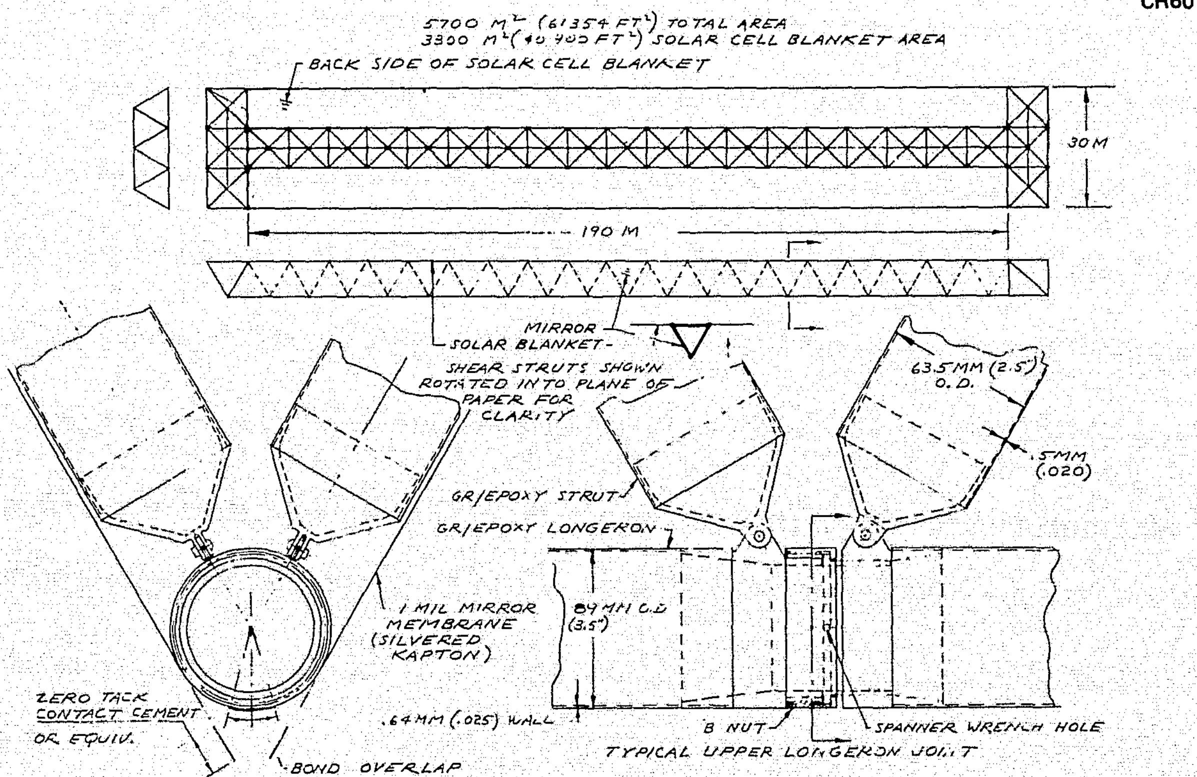

Figure 4-11. 456-kW Power Platform

shadow, with large differences in coefficients of expansion and heating and cooling rates between the blankets and center beam.

With a blanket tension of 58.4 newtons per meter and a blanket mass of 1 kg/m^2, the membrane frequency of a 190m length of blanket (attached only at the ends) is 0.02 cps (50-second period). Since this is 10 times the control frequency (period approximately 10 minutes), this tension in the blanket membrane precludes coupling with the SCM control system.

Two array configurations are possible with the structural arrangement shown in Figure 4-11. The sides of the triangular center beam can be covered with mirror membrane to provide a solar concentration factor of N = 1.5 for the two 10m-wide blankets. The combined weight of the blanket and mirror membranes is 3944 kg (8695 lbs) for this configuration. An alternate configuration with the same structural arrangement, to eliminate the mirror membrane and use three 10m-wide blankets, has a weight of 5700 kg (12,566 lbs).

Although the mirror surfaces complicate assembly of the power platform, their use lowers the array cost per kilowatt because of the savings in solar cell blanket. Mirror membrane surfaces have been shown in every SPS configuration. Hence early orbital experience with them is desirable. For these reasons they are selected for this assembled configuration of the power platform.

Since the weight and volume of the launch package required for the assembled 456-kW power platform is small compared to the Orbiter capability, the power platform must be launched with another element of mission hardware to fully utilize the Orbiter. Launching the power platform with the SCM represents a particularly attractive combination because it maximizes the SCB capability achievable with a single Orbiter launch. The initial version of this launch combination is shown in Figure 4-12. The description which follows applies to this initial version of the SCM launched with the power platform.

The overall length of the SCM is 16.26m (640 in.), which is close to the maximum length compatible with launch with the Orbiter docking module.

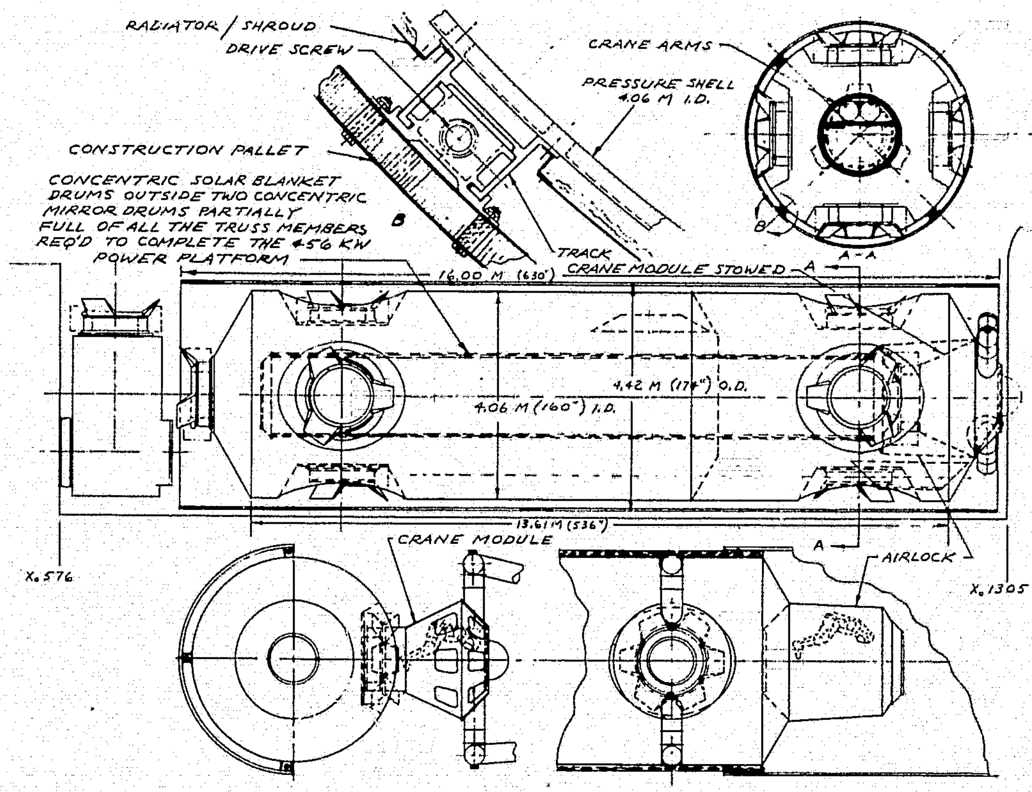

Figure 4-12. Single Launch of SCM and Power Platform — Initial Configuration

The SCM contains eight radial berthing/docking ports and one end docking port. The Orbiter docking system is shown to make any port compatible with the Orbiter docking module without an adapter. One of the forward radial ports is used for the crane module, and two of the aft radial ports are used for the power platform in the balanced configuration, so that six ports remain available after completion of the first mission. An alternate trail configuration, shown in Figure 4-13 with the balanced configuration, leaves seven ports for Orbiter docking or mission element berthing after completion of the PP assembly.

One candidate buildup sequence from the many options possible is shown in Figure 4-14. The SCM is launched with a large EVA airlock mounted on the forward conical bulkhead. The airlock is used for structural support of the concentric solar blanket and mirror rolls which are bolted to it. The innermost mirror roll, whose inside diameter is 1.52m (60 in.) contains the truss members required for the complete power platform structure as well as the crane arms. The truss members require about 66 percent of the cylinder's cross-sectional area for packaging with no nesting of shear struts and longerons.

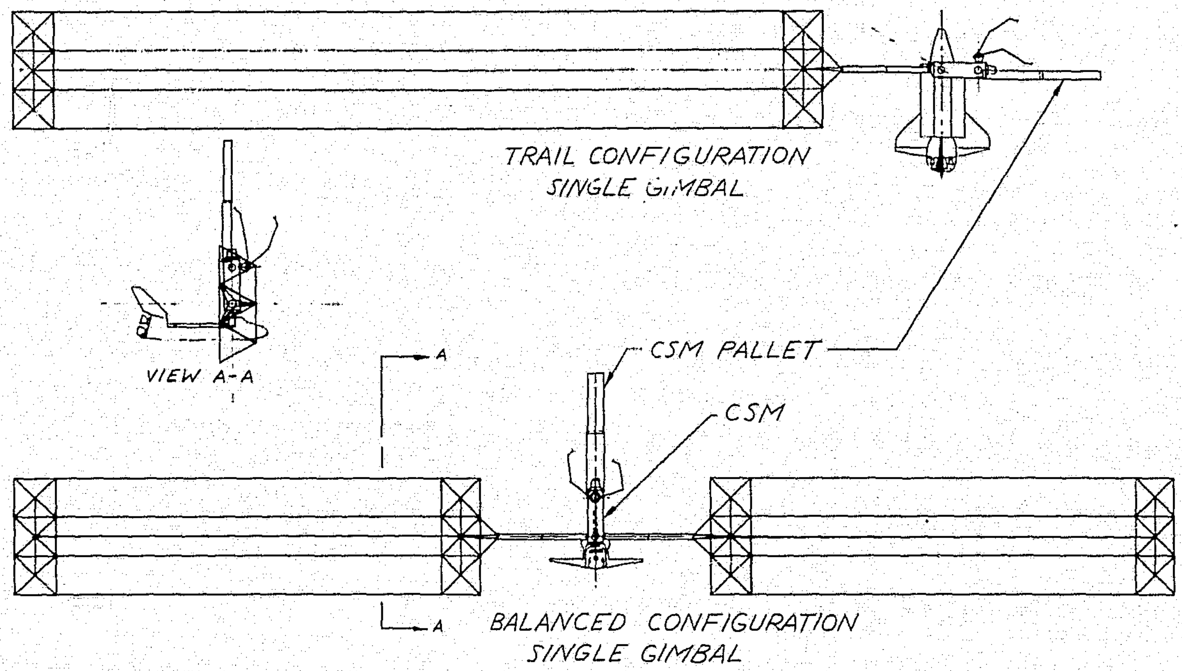

Figure 4-13. CSM and 456-kW Power Platform in Single Launch

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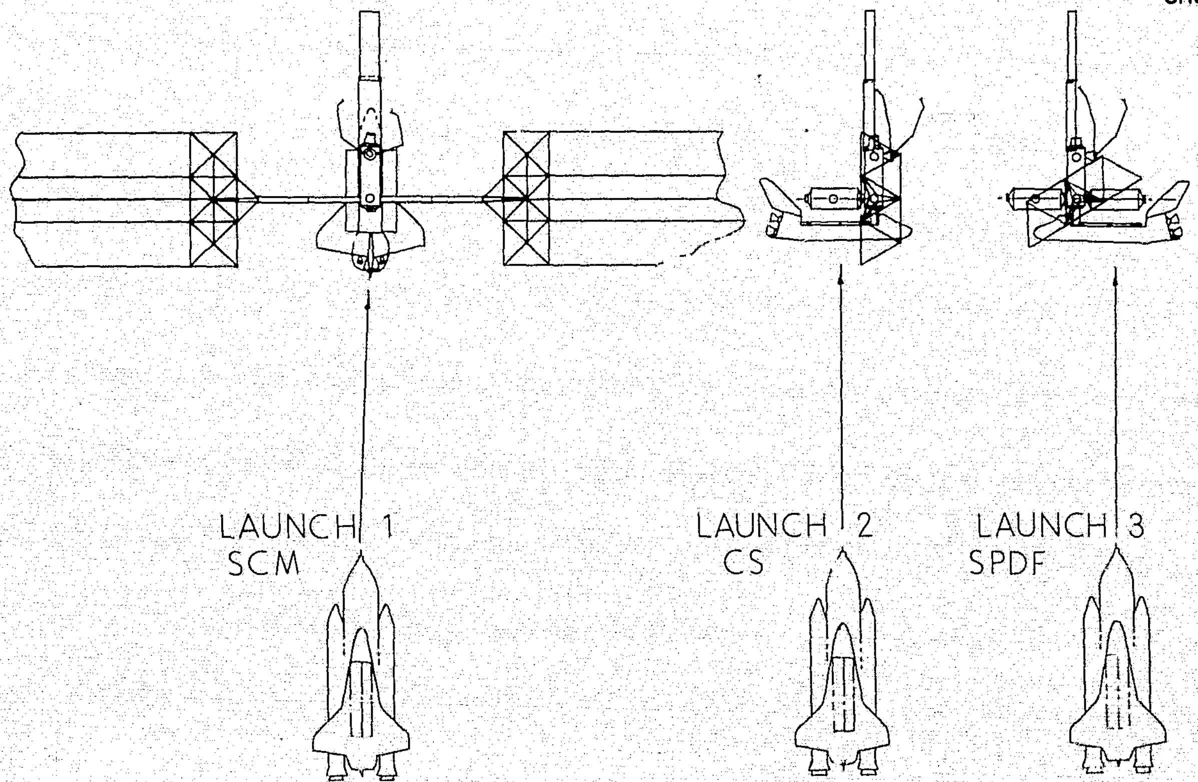

Figure 4-14. CSSCB 456-kW Power Platform in Single Launch

This SCM with its pallet, EVA airlock, crane module, cherry pickers, and power platform, supplies in a single launch the power and space assembly capability to satisfy the assembly and LEO test requirements for TA-1, TA-2, or the 30m radiometer.

4.1.4 Fabrication and Assembly Configurations

The fabrication and assembly concepts developed are based on fabricating the major portion of the power platform structure while delivering solar cell blankets, reflector blankets or mechanisms. During the course of the study, candidate power platform sizing has ranged from 150-kW to 500-kW levels. Test Article 2 prototypical considerations were also employed. Some configurations lend themselves to the full power range by length scaling, while others are generally practical for either a small-only or large-only array. In-situ construction (build in place) potentials were also examined.

The concepts described here include:

A. A ladder structure — 150 kW to 500 kW.

B. A 10m triangular truss — 150 kW.

C. An array geometrically similar to TA2 — 500 kW.

D. An in-situ 8m wide array — 150 kW.

4.1.4.1 Ladder Concepts

The ladder concept is a simple structural approach which resembles a JSC ladder structure concept. This configuration (Figure 4-15) is a flat planar structure consisting of four longeron beams and several transverse beams with solar cell blankets suspended in the open bays of the assembly. For the single-launch packaging concept developed, the maximum array width is 28 meters. For power levels between 150 kW and 500 kW, the length of the array varies from 65 meters to 200 meters. The distance between transverse beams will vary between 30 and 50 meters. Within these various limits the fabrication and assembly concept will accommodate a wide range of geometric proportions to meet any power level size. The configuration defined uses beams which are fabricated, essentially in place, of graphite-epoxy or graphite-polyimide composite materials from a locatable fabricating module. The two-piece pallet for transporting the system and materials within the Orbiter is unfolded and mounted on a CS berthing port (or the Orbiter

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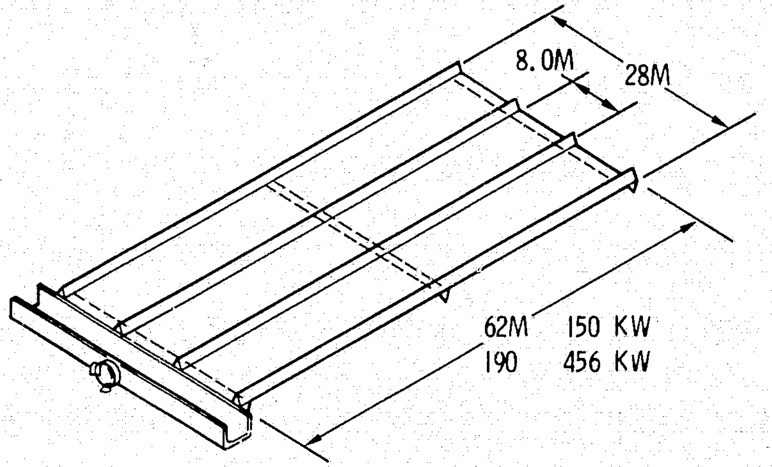

Figure 4-15. Ladder Concept for 150-500-kW System

docking module in a sortie mode) where it becomes the fabrication and assembly fixture for the array. The beam fabricating module is removed from within and placed at a beam position on the side and the solar blanket rolls are relocated (Figure 4-16). The fabrication module is moved to each longeron position until all four are completed, as shown in the fabrication/assembly sequence (Figure 4-17). The fabrication module is then located on

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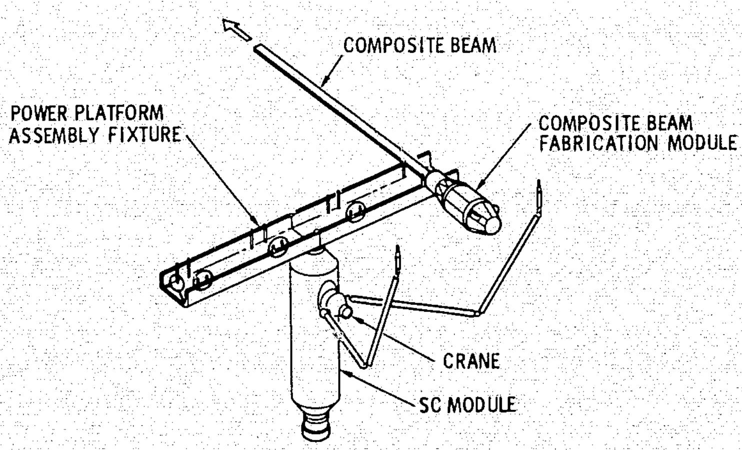

Figure 4-16. Fabrication and Assembly Equipment for the Power Platform

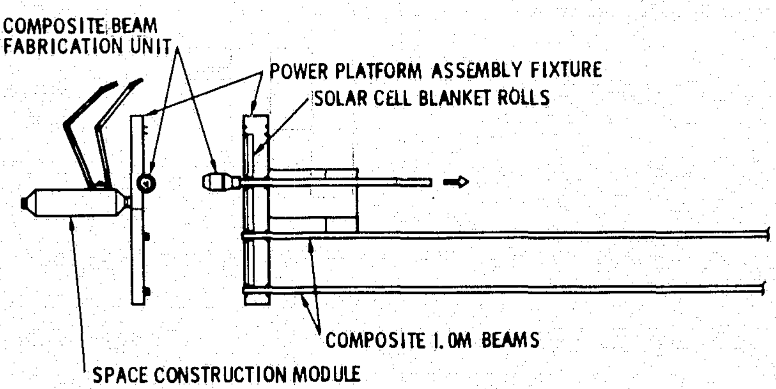

Figure 4-17. Ladder-Concept Longeron Beam Fabrication Power Platform Construction

the end of the fixture and a transverse beam is fabricated and attached to the longerons. The solar cell blankets are attached to the cross beam and the array is moved through the holding fixtures. As the blankets unroll they are periodically attached to the longeron via a system of negator springs. At an appropriate span the array is stopped and another cross beam is fabricated and attached to the longerons (Figure 4-18). The blankets may be attached to these cross beams. The method of attaching the beams to each other is illustrated in Figure 4-19 and 4-20. When the array is complete and the blankets are attached to the closeout cross beam, the longerons are rigidly attached to the pallet/assembly fixture. The blanket rolls can be removed and used as a standoff mast for mounting the power platform on the SCB facility.

The most critical design conditions for this concept are in the large (456 kW) size. An array of this size results in a PP gross liftoff weight of approximately 10,000 kg; as an Orbiter payload, the addition of the beam fabricating module results in a total liftoff payload of 10,875 kg. This flat array structure is more flexible than most concepts. However, it should have a natural frequency between 0.02 Hz and 0.16 Hz, depending on the fixity of the support structure. This is sufficiently higher than the anticipated control frequency to be acceptable.

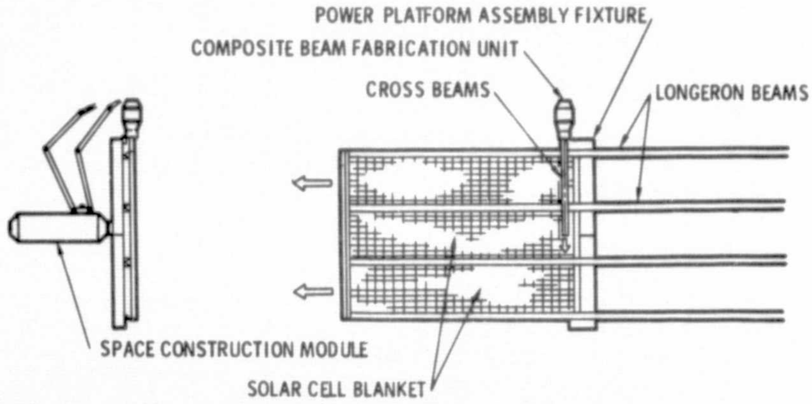

Figure 4-18. Ladder-Concept Array Assembly for Power Platform Construction

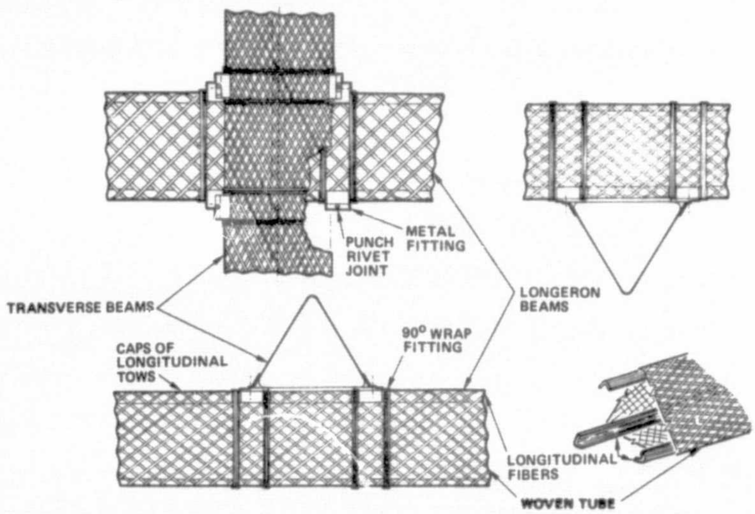

Figure 4-19. Composite Beam and Joint Detail

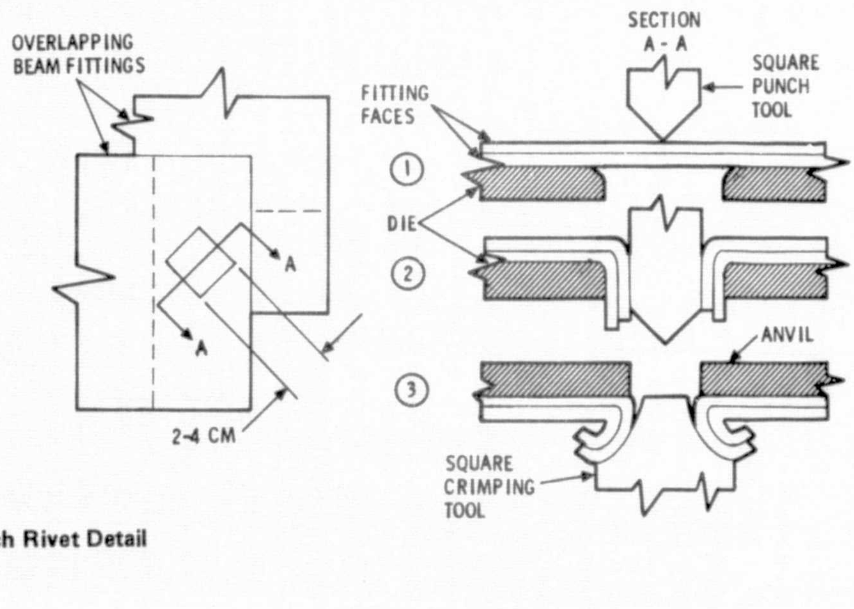

Figure 4-20. Punch Rivet Detail

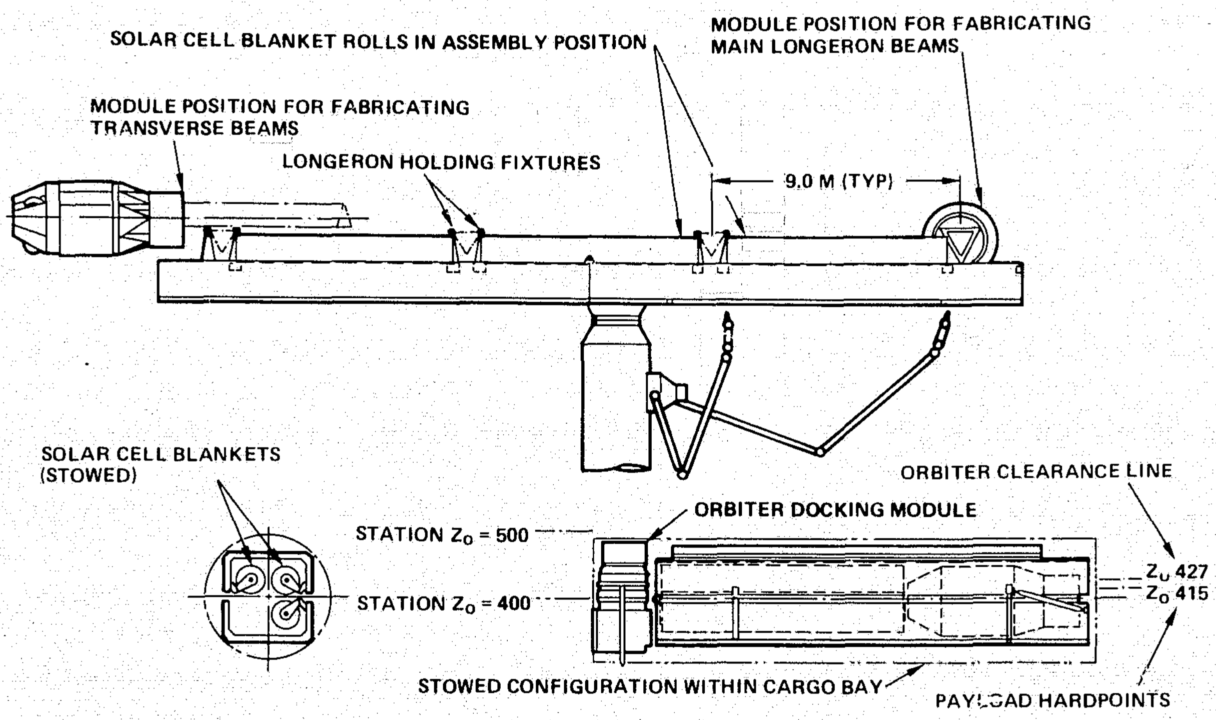

Figure 4-21. Fabrication/Assembly Tooling for 150-500 kW Power Platform-Ladder Concept

4.1.4.2 Ladder Concept Fixtures

The ladder array concept is built up entirely with the use of a single assembly fixture. This fixture performs as the carrier pallet during boost phase for the system elements and later becomes the primary structural interface for the power platform. It consists of two channel shaped structures hinged together (Figure 4-21). The mechanisms for holding and moving the longeron beams, the fittings for mounting the beam fabrication module and the fittings for mounting the solar cell blanket rolls are contained within the channel structures. Exterior to this is a berthing port or other interface for mounting the fixture.

4.1.4.3 Fabrication Equipment

The sole element of fabrication equipment is the module which fabricates the 1m triangular section beams which are prototypical of TA-2 longerons. This module (Figure 4-22) consists of a structure with a centerline triangularly shaped mandrel, reels for longitudinal corner tows, a rotating loom for laying material tows in an open double helix on the mandrel, furnaces for curing

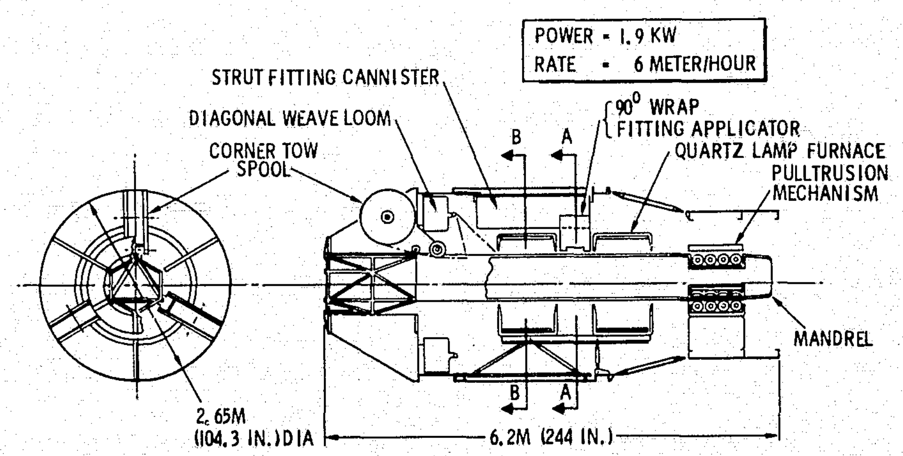

Figure 4-22. Fabrication Module – 1m Beam Composite Constructions

the composite, a fixture for installing fittings for joining beam elements, and finally a mechanism for pulling the beam from the mandrel. Thermal energy carriedout of the furnace by the fabricated beam is the largest makeup energy of the module, which consumes a total of approximately 1.9 kW electrical power for a production rate of 0.1 meter per minute. For this reason, the module power requirement is very sensitive to production rate, as is the length of the furnace necessary to provide the appropriate cure times. While the design concept illustrated utilizes pre-cured (zero tack) epoxy tows, the identical concept can be adapted to thermoplastic tows by moving the fitting applicator in front of the first oven and replacing the second oven with a heat exchanger.

4.1.4.4 Prototypical Triangular Truss Concept

The same equipment may be used to build a truss array structure having the same basic geometry as one half of the TA-2 solar collector. This is a triangular truss (Figure 4-23), 10m on a side, with strut-assembled corner caps which are 1m triangular beams and which are the same as defined in the ladder concept. The manner in which the ladder concept fixture may be used for this concept is evident from the figure. The only addition is the diagonal strut tubes which are carried in trays on the sides of the pallet and which are manually installed in the assembly via EVA operations. This concept yields an array which is 10m wide (8m solar cell blanket) and therefore is limited to 150 kW range for sizing because of practical limits to the length of the array.

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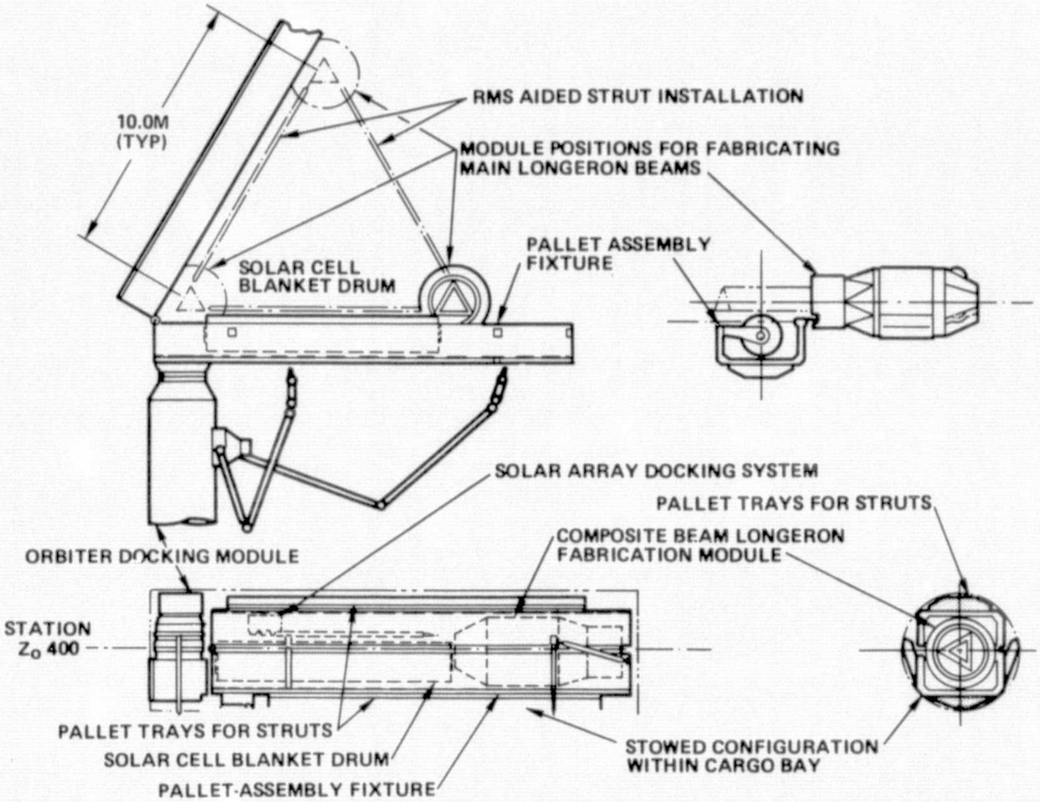

Figure 4-23. Fabrication/Assembly Facility for 150-kW Power Platform-10M Beam Prototypical

4.1.4.5 Test Article 2 Prototype Solar Collector

This concept is identical to the geometry and arrangement of TA-2 described in Part 2 of the study, except for length. The same kinds of fixtures are necessary. However, as conceived here the corner cap beams are composite material instead of aluminum. The fabrication module is therefore similar to that described above rather than the metal forming module defined for TA-2 in Parts 1 and 2 of this study. For further description refer to the TA-2 definition in the Part 2 interim reports.

4.1.4.6 In-Situ Construction Concepts

As part of the study of 150-kW array candidates, consideration was given to a concept of building the array in place. The primary constraint was that it should be a two-wing double-gimballed array no wider than the module (CSM) on which it was mounted and that it should involve no more than one Orbiter launch. The concept as shown in Figure 4-24 uses a fixture consisting of a cylindrical structure having a single role axis gimbal within it, a berthing interface on one end and two folding trusses on the other end. The end of

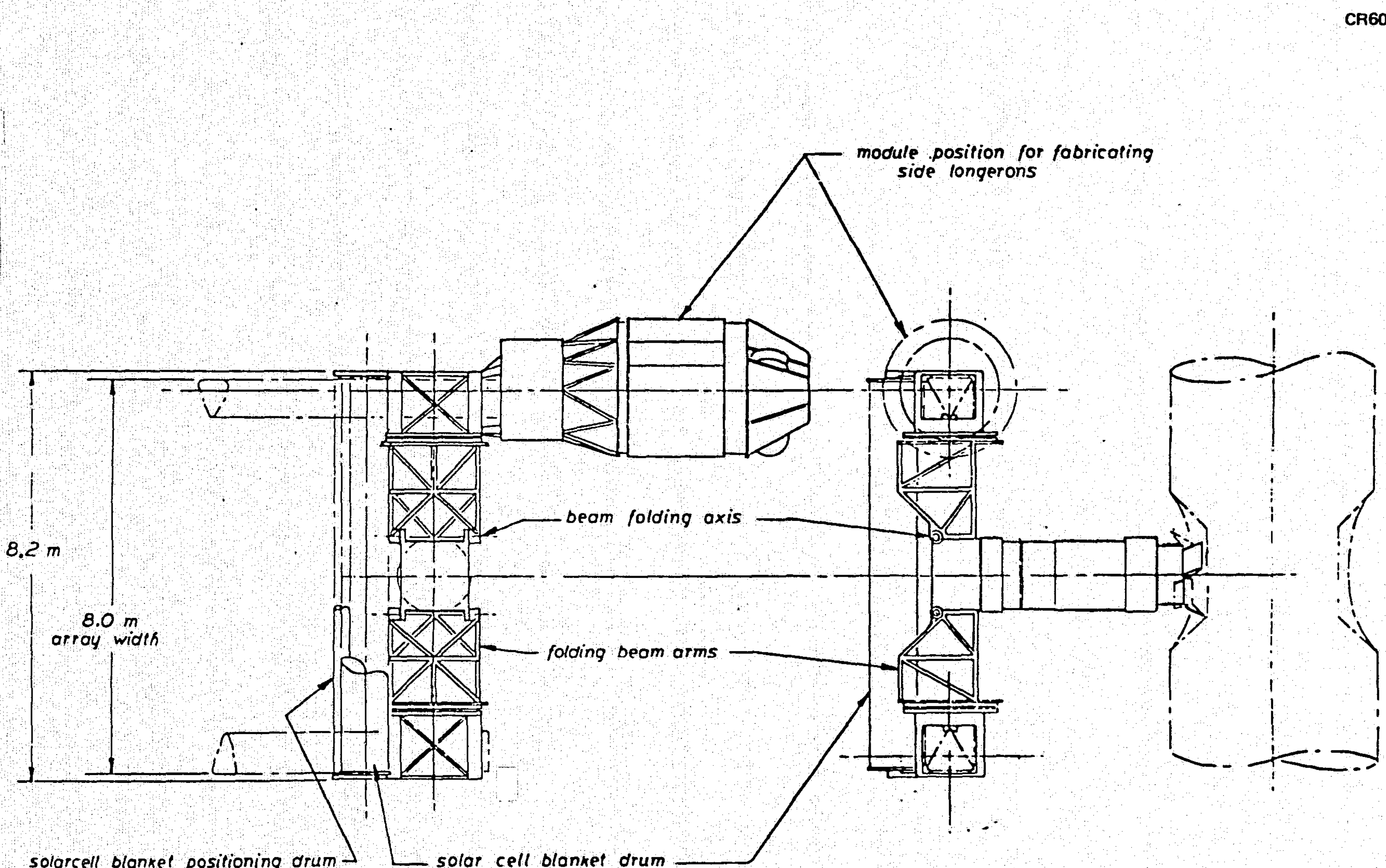

Figure 4-24. 150-kW Power Platform In Situ Construction

each truss has a fixture which is roll gimballed on the truss, and mounts the 1m triangular beam fabrication module and the mechanism to support and control the beams. The array is fabricated at a right angle to the support mast in a manner similar to that of the ladder array. When complete, the beams are rigidly attached to the end gimbals, resulting in an array wing with two gimbal axes. It is sized so that two fixtures and the fabrication module can be carried as a single Orbiter payload.

4.2 TA-1 ANTENNA

The TA-1 antenna consists of two long crossed arms mounting pairs of wave guides, amplitrons, and phase control electronics units. The horizontal arm is 123m long and the length of the vertical arm is 126m. To minimize the cost of TA-1, the arms are fabricated and assembled on the ground in lengths compatible with the Orbiter cargo bay. The 123m horizontal arm is divided into seven segments, each 17.57m (57.65 ft) in length. The 126m vertical arm is divided into eight segments that are 15.75m (51.67 ft) long. Each panel segment, with its structure, waveguides, amplitrons, and power distribution system, is completely assembled on the ground and folded as shown in Figure 4-25 for launch. The shear strut spacing for each segment

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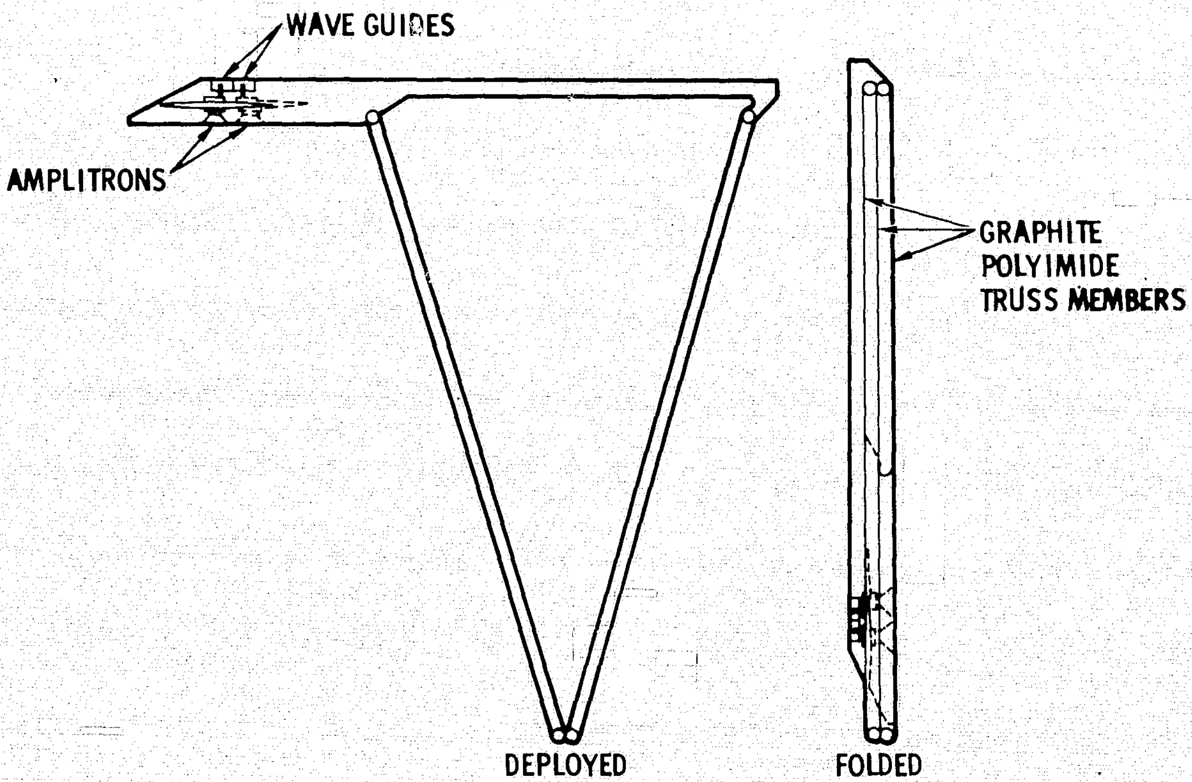

Figure 4-25. TA-1 Panel Deployment Concept

is selected so that the amplitrons fit between the shear struts with the segment folded. The seven panel segments of the horizontal arm and the eight panel segments of the vertical arm are mounted on a launch pallet which serves also as the jig for orbital deployment and joining of adjacent panel segments. A cross section of the launch package is shown in Figure 4-26. The launch pallet is divided into two sections which are hinged together at one end. Each section extends nearly the full length of the cargo bay so that when the sections are hinged open, their combined length is more than twice the length of a 17.57m horizontal-arm panel segment.

The 23 phase-control-electronics units are stowed along both sides of the launch package. The individual units are bolted together to form a beam for launch and the ends of the beam are attached to the bulkhead frames on the pallet which mounts the orbiter interface trunnions.

The TA-1 deployment/assembly sequence is shown in Figure 4-27 with an itemized description of the sequence of events. Since the length of the launch pallet is established by the length of the horizontal arm segments which was

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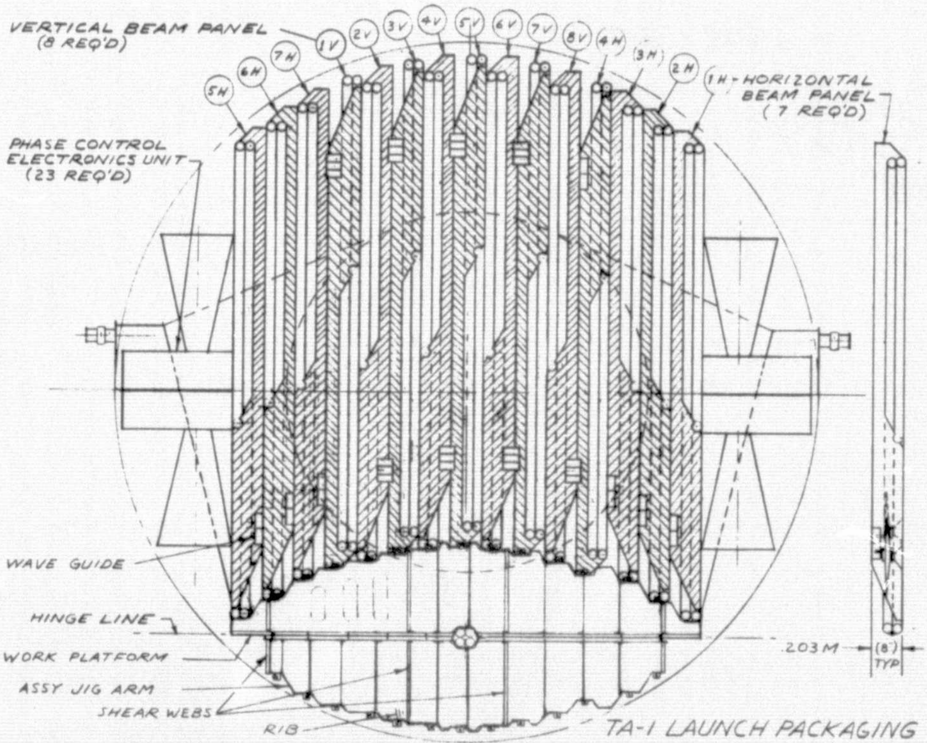

Figure 4-26. TA-1 Launch Package

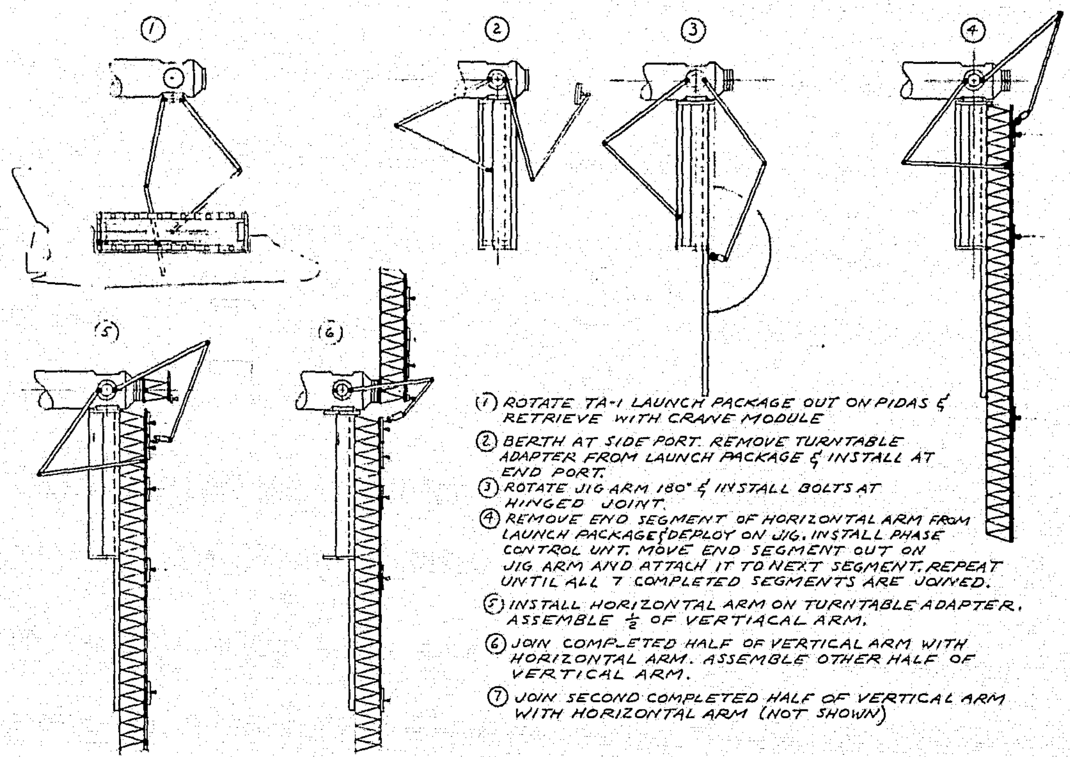

Figure 4-27. TA-1 Deployment Sequence

selected to minimize the number of segments which must be handled and joined, the pallet with its end berthing port extends nearly the full length of the cargo bay. This requires use of the crane module for retrieval and berthing. If eight horizontal and nine vertical arm segments were used instead of seven and eight respectively, the length of the pallet could be compatible with the Orbiter docking module. The Orbiter could then be docked prior to berthing the TA-1 launch package, and the Orbiter RMS could be used for berthing. Since the crane module is required for TA-1 deployment and assembly, it was used for hand-off and berthing to permit use of the full length of the cargo bay. If payload hand-off is included in the STS repertory of operational procedures to eliminate the 2.44m (8 ft) length restriction imposed by the docking module, the benefit to the 30m radiometer is far more pronounced than for TA-1, but the packaging for most program elements is clearly simplified.

Isometric views of the TA-1 deployment sequence are shown in Figure 4-28.

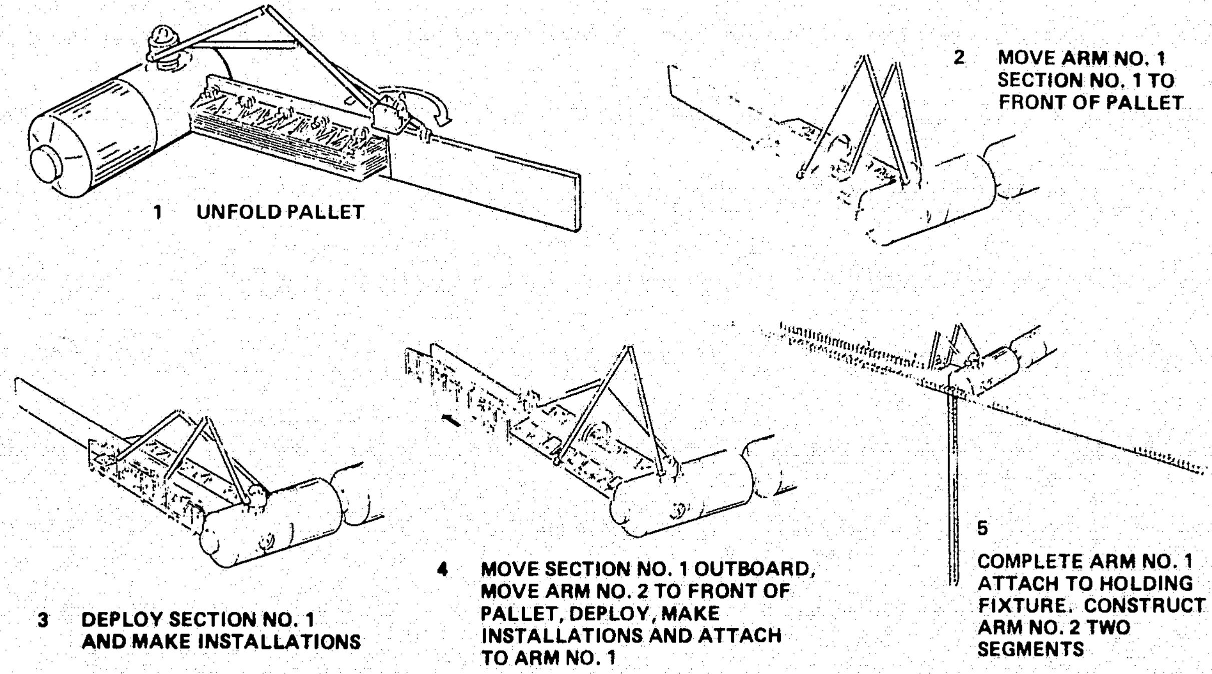

Figure 4-28. TA-1 Deployment Sequence

4.3 TA-2 ANTENNA

The concept for the TA-2 antenna that was previously reported (Part 2 of the study) was for an on-orbit fabricate and assemble mode (Figure 4-29). Part 3 examined deployable structures and a deployable concept was developed for the TA-2 antenna. The TA-2 antenna was segmented to allow several rows of trusses to be folded and packed as flat assemblies in the Orbiter bay. The rows of trusses extend the length of the antenna — 15 meters. Each assembly (Figure 4-30) consists of one row of five 3m-by-3m waveguide panels with attached amplitrons and standoff structural fittings, one row of upper truss members, two rows of intermediate truss members, and one row of lower truss members. The various truss members are made of graphite-poliyimide tubes which are light, stiff and heat-resistant. The hinges on the edges of the truss rows are aluminum, as are the waveguide standoff fittings.

The panels of waveguides are built to a high degree of flatness and may be checked out on the ground for RF alignment and transmission with the attached amplitrons. Each panel as a whole may be aligned with other panels by means of adjustable attachments to the standoffs at three places on each panel.

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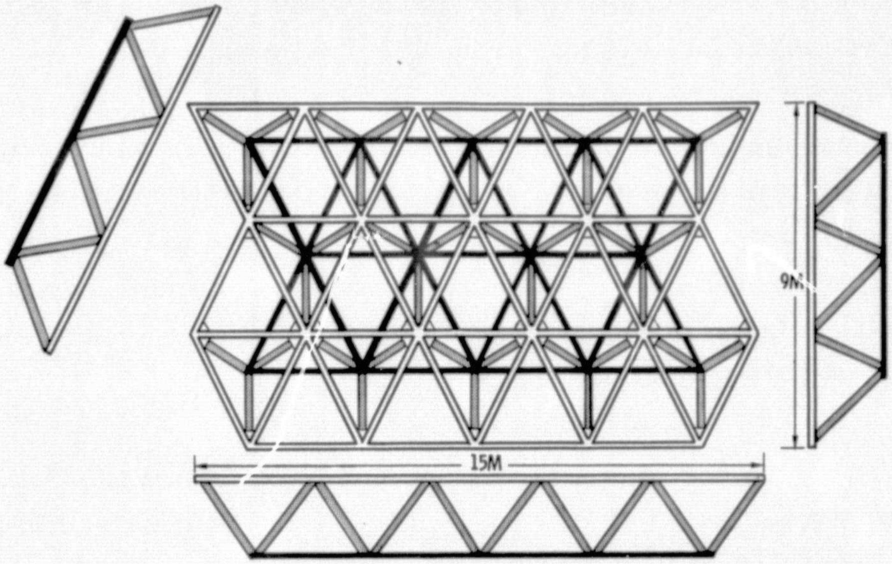

Figure 4-29. Graphite-Polyimide Antenna Truss Structure

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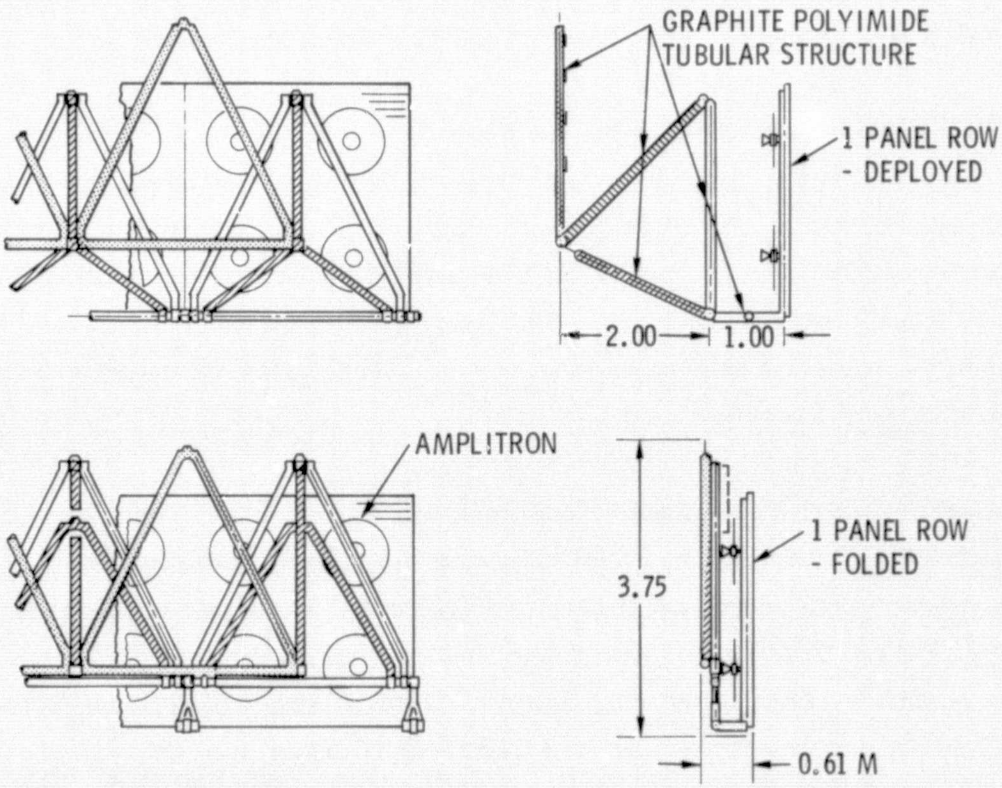

Figure 4-30. Deployable TA-2 Antenna

Phase control electronics modules are attached to the opposite side of the basic truss structure in order to provide maximum protection from the heat generated by the RF transmission. Each module is also protected by a thermal heat shield in the shape of a truncated cone.

The three packages of waveguides plus truss structure and the 15 phase control electronics modules occupy only about three-fourths of the payload bay cross section. The remaining payload space can be used for transporting 30 of the solar collector frames which exceed the two-launch capability required for the rest of the collector frames. The antenna components are mounted on a pallet which has a berthing port.

Figure 4-31 shows the sequence of deployment operations. The antenna payload pallet is first attached to a berthing port on the construction support module, and beams which act as an assembly fixture are deployed. The stowed antenna truss assemblies are then removed from the pallet, attached to the assembly fixture and erected. The trusses are attached to each other as they are erected until the complete 9m-by-15m truss assembly is complete. The gimbal structure is attached and exercised. The phase control electronics are installed and a complete checkout performed.

4.4 100-METER RADIOMETER

To conduct passive microwave radiometry, Outlook for Space called for an antenna system to provide earth resources data with a resolution of 1 km at an altitude of 800 km. Based upon the design requirements outlined in Section 3.4, a design concept for a 100m radiometry satellite evolved. The antenna type selected is a parabolic torus-electronically scanned system with an effective aperture of 50 percent.

The construction of the antenna is shown in Figure 4-32. The base frame, base support beams, and parabolic longerons are assembled from collapsible composite truss sections as shown in Figure 4-33. Each truss section is composed of graphite polyimide tubing which, when deployed, forms a section 2m by 2m by 18m maximum length. End joints utilize turn-buckle adjustment to accurately adjust the geometry during assembly. The radiometer's reflective surface is a metallic mesh deployed from rolls that is stretched between preformed circular Z-frames fabricated from compos-

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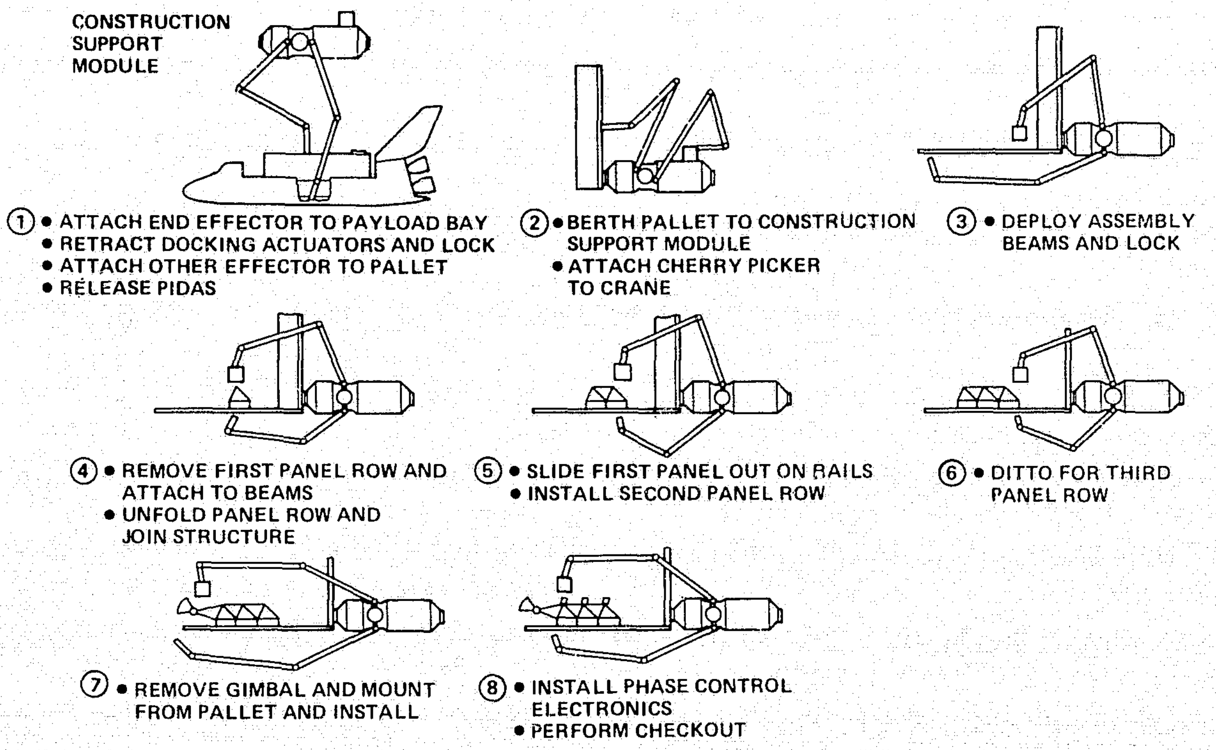

Figure 4-31. TA-2 Antenna Deployment Sequence

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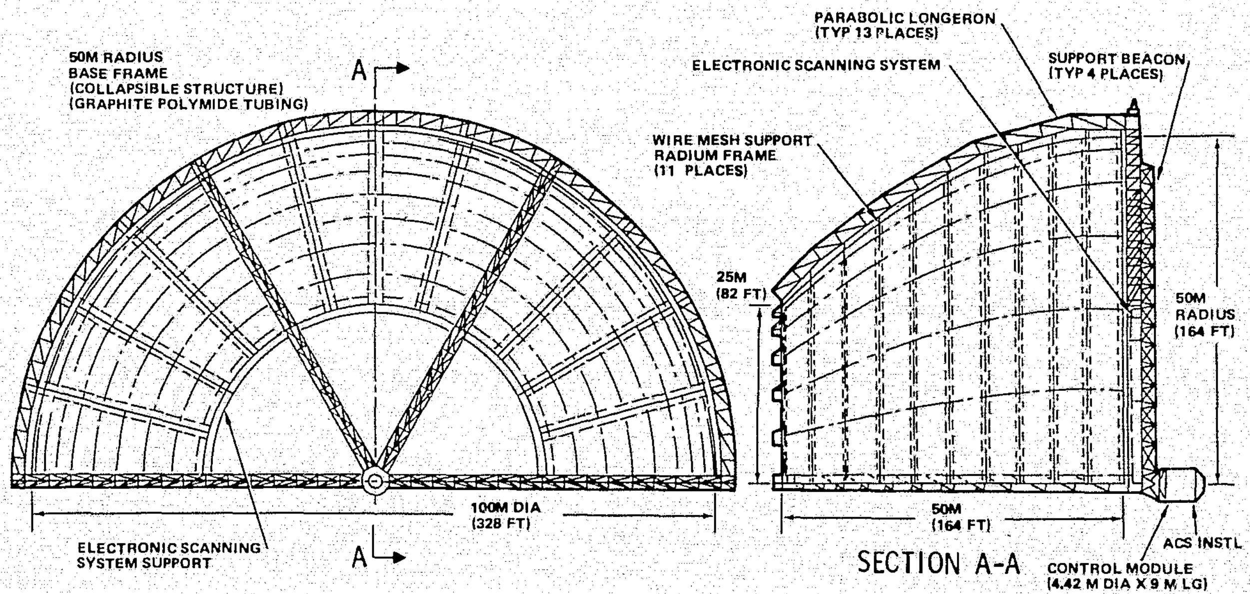

Figure 4-32. Electronically Scanned 100m Parabolic Torus Radiometer

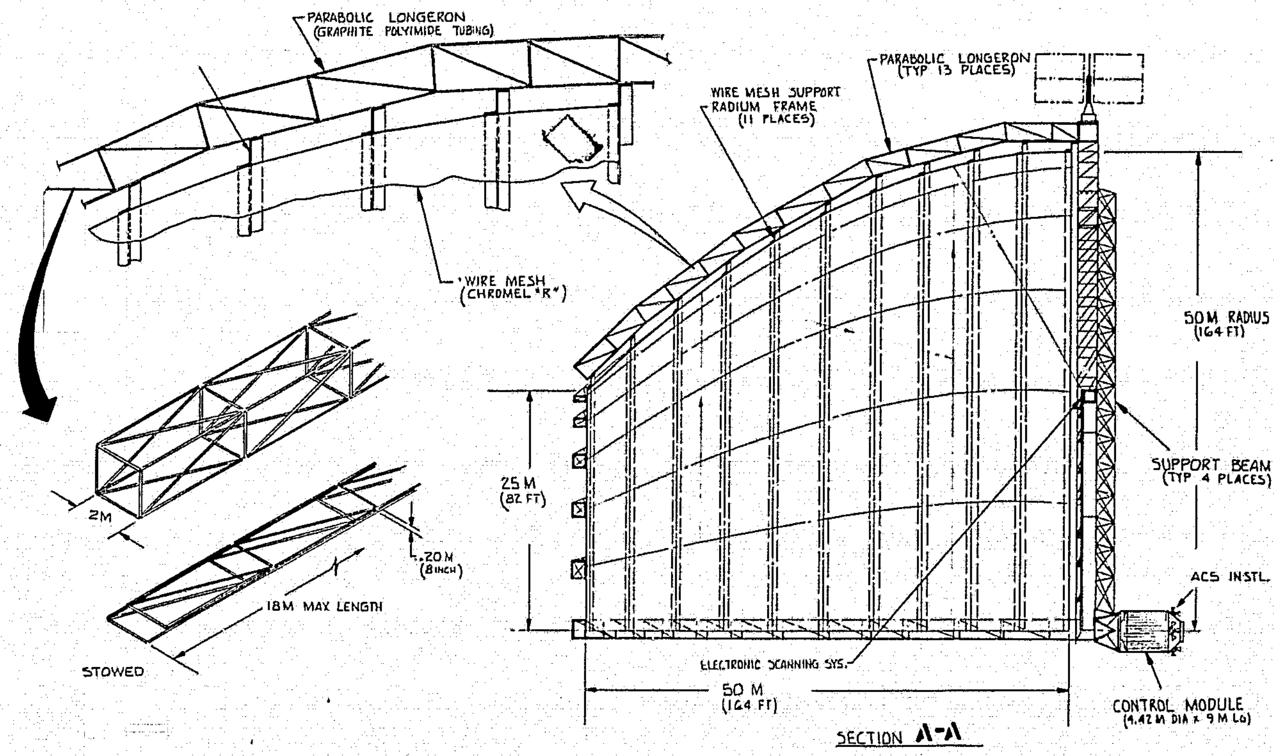

Figure 4-33. 100m Parabolic Radiometer

ite material. The wire mesh has a thin gold coating, a few microns thick, on one surface to provide low thermal absorption and emission. The other surface is coated with paint, providing similar characteristics to prevent warping of the reflective surface. The electronic scanning feedhorns are supported by six preformed composite "box" sections 1.5m by 1.5m by approx. 12m long supported by the four base support beams. The feedhorn sets are installed at a radius of 50m from the face of radiometer and over a 120 degree arc.

The satellite control module is 4.42m in diameter by 9m long, utilizing the identical structural characteristics selected for the SCB modules. Satellite power is supplied by a deployable solar array installation with 45.5m^2 surface area.

Assembly of the 100m radiometer, as shown in Figure 4-34. is facilitated by a turntable and an adapter which allows rotation about its axis in two different orientations with respect to the strongback. Initial assembly involves

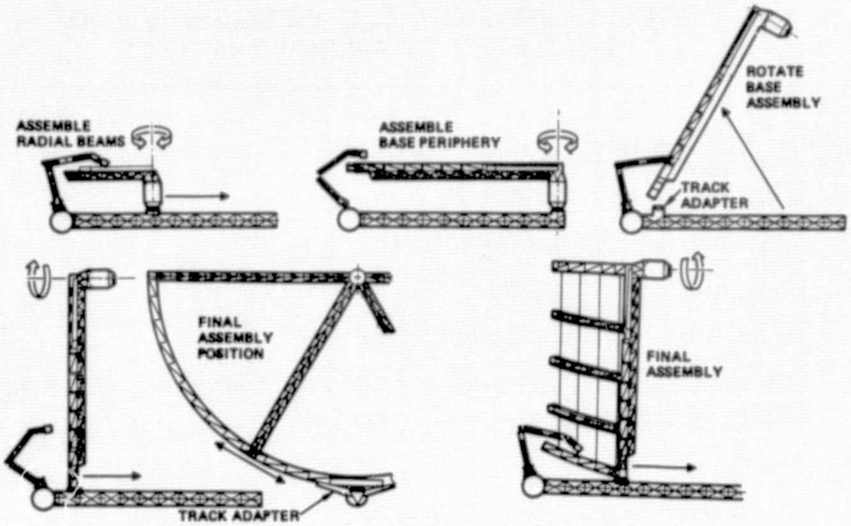

Figure 4-34. 100m Radiometer Assembly

placing the satellite control module on the strongback turntable and installing the four base support beams, 50m radius base frame, the electronic scanning support system, and the electronic scanning system. Translation along the strongback is utilized in conjunction with turntable rotations to keep all work stations within easy reach of the 35m crane. Following assembly of the base periphery elements, the assembly is rotated 90 degrees, as shown, and placed in a track adapter affixed to the turntable. While in this position, the longerons, mesh support frames, and the mesh sections are installed for each antenna segment. Upon completion of the parabolic torus antenna assembly, the completed radiometer is rotated and placed on the turntable for test. The solar array power system is installed prior to radiometer separation from the SCB in preparation for transport to higher orbit.

4.5 SPACE PROCESSING DEVELOPMENT FACILITY

The general characteristics and capabilities of the Space Processing Development Facility (SPDF) are highlighted in Table 4-3. This particular facility will be most useful in a spaceflight demonstration program aimed at reducing risk of space processing operations as a precursor to private capital investment in process optimization. Eventual pilot plant operation and full-scale space production will evolve as space operations become commercialized.

Table 4-3

SPACE PROCESSING DEVELOPMENT FACILITY CHARACTERISTICS

Processing Equipment
• Containerless furnaces
• Continuous-flow electrophoresis units
• Cell culture chamber
• Analytic work station
• Optional small animal colony for bioassay and source of fresh cells
Crew Systems
• Environmental monitoring
• Special garments
• Emergency equipment
Facility Subsystems
• Shirtsleeve environment module
• Integral radiator ~ 12 to 35 kW rejection
• Power in 8-15 kW range
• Storage provisions for up to 90-day missions with 1-2 crew

The basic module subsystem is derived from Orbiter, Spacelab and payloads for Spacelab equipment programs. The processing equipment is directly available from the space processing activity (SPA). Onboard analysis capability, a key feature of the facility, will be added to the SPA equipment and derived from commercially available ground laboratory counterparts.

The spaceflight activities planned for the facility involve missions ranging from 30 to 90 days in duration. During this mission processes suitable for production, as contrasted to purely scientific research, are evaluated. Stress will be placed on demonstrating repeatability, quantity, uniformity, and efficiency parameters which are crucial to attract commercial interests to space processing.

A representative view of the SPDF is shown on Figure 4-35. The facility is divided into two compartments by a pressure bulkhead and hatch. This feature provides for isolation of the processing area from other portions of the module and the station.

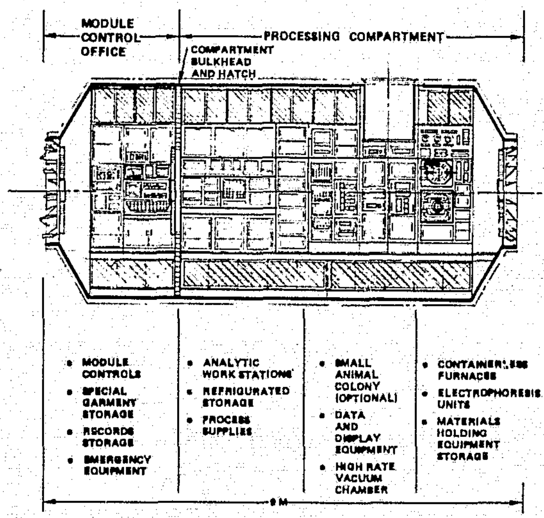

Figure 4-35. Space Processing Development Facility Concept

The processing equipment shown is used primarily with inorganic materials such as shaped crystals and ultrapure glasses. The process work station associated with the containerless processing equipment is used to prepare samples for furnace treatment and characterize materials after processing. On-board analysis for both biomaterials and inorganics capability is a unique feature of the facility.

The opposite bay of the module, not shown on the chart, includes equipment for bioprocessing development. Separation devices such as electrophoresis units, along with cell culturing capabilities, are available. As an option, small-animal holding equipment provides colonies of live research subjects and the onboard capability to perform bioassay tests and as well as to supply sources of fresh culture media.

Section 5
SPACE CONSTRUCTION BASE ANALYSIS, DESIGN AND CONFIGURATION

5.1 SYSTEM REQUIREMENTS ANALYSIS

Using the study Part 2 SCB design data case, selective SCB requirements were relaxed to reflect the basic philosophy of an SCB concept based on a low-cost reduced-complexity construction shack approach. The basic modules will utilize:

- Reduced crew support, relative to prior Phase B studies, that is still fully consistent with safety and performance requirements
- Relaxed subsystem operational performance and tolerances
- Fail operational/fail-safe design for critical subsystems

The subsystems will maximize the application of off-the-shelf hardware with replacement and maintenance being consistent with this approach. All subsystem elements will be compatible with Shuttle-tended operations and possess growth capability for continuous manning.

Figure 5-1 illustrates the growth activity flow and the sources of information and data used to establish this objective.

5.1.1 Assessment and Integration of Shuttle System Requirements

The operational requirements of the Shuttle which impose design and operational considerations on the SCB include module size, mass, CG location, orbital stay time, logistic resupply periods, logistic subsystem, and crew size.

The payload bay envelope of 4.45m diameter with a maximum length of 18.28m is adequate for meeting the functional requirements of the SCB modules which are all less than maximum length. Normally, the SCB habitable modules allowed for the installations of the Orbiter's docking module in the cargo bay. However, for delivery of structural elements for

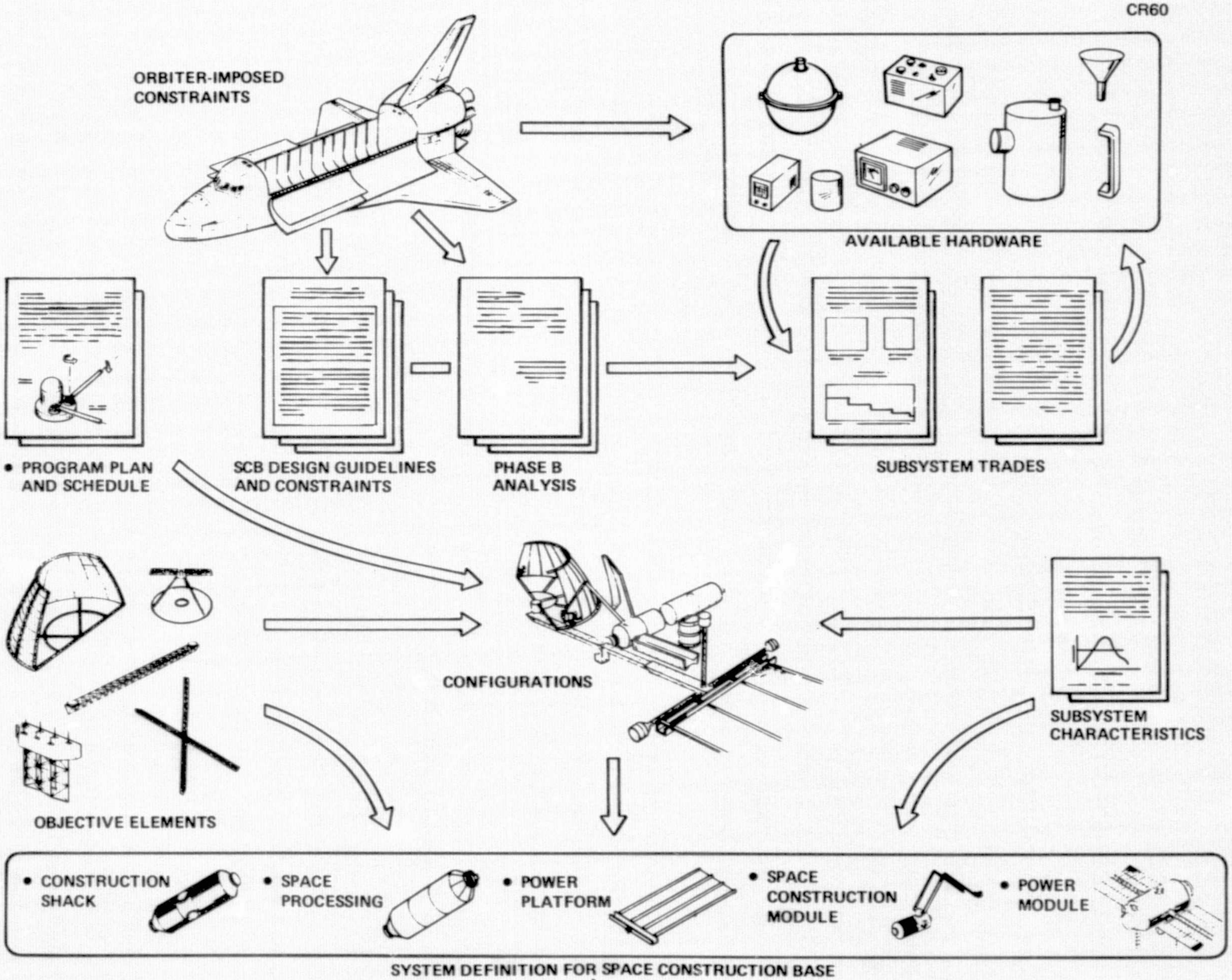

Figure 5-1. Integration of System and Subsystem Requirements

deployment and assembly of objective elements this is a limiting constraint. With this type of construction, the Orbiter's payload is normally volume-limited due to the low-density structural elements packaging characteristics. Therefore, the larger the percentage (e.g., longer structural members) of the structure that can be accommodated on each launch, the lower the number of required launches — reducing total program costs. These payloads also present a CG balance problem due to their normal uniform longitudinal density, and the use of the entire cargo bay tends to shift the payload CG, forward and to the CG envelope limit. In some cases, ballast may be required. The orbital capability of 29,545 kg (65,000 lb) is not a constraint as the large complex modules/cargos are approximately 15,900 kg (30,000 to 40,000 lbs). The primary Orbiter driver on the SCB is the free volume within the Orbiter available for logistic resupply. This appears to be approximately 60 days for seven men, and in the Shuttle-tended mode the maximum Orbiter duration capability is 30 days with kits. This logistic concept is based on pumping liquids and gases from the Orbiter with the dry consumables being transferred by the crew to the SCB.

5.1.2 Orbiter Hardware Applications

A significant amount of Orbiter hardware can be used in SCB subsystems although some modifications may be necessary. The main advantages of using Orbiter hardware includes (1) significant savings in DDT&E and (2) reduced program risk by the use of proven designs.

Minimal on-orbit maintenance is planned for the Orbiter due to the relatively short seven-day design mission. Conversely, the long-term on-orbit operation of the SCB will require maintenance, and therefore SCB subsystems containing Orbiter hardware must be modified to meet this requirement.

Figure 5-2 gives the number and type of applicable hardware. As indicated a significant amount of Orbiter hardware, 50 to 60 per cent can be used to satisfy SCB subsystem requirements.

5.1.3 SCB Subsystem Components Physical and Operational Characteristics

Figure 5-3 identified key concept selections for each of the SCB subsystems.

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BENEFITS/CONSIDERATIONS OF USING ORBITER HARDWARE

- PRIMARY SAVING IN DDT&E OF SIMILAR ITEMS
- PROVEN RELIABILITY
- OFF-DESIGN-POINT OPERATION

SUMMARY OF APPLICABLE HARDWARE (UNMODIFIED AND MODIFIED)

SUBSYSTEM	% APPLICABLE	TYPICAL
• ECLSS	40-50	• PRESSURE CONTROL, TANKS, HEAT EXCHANGERS AND VALVES
• ELECTRICAL POWER	5-10	• INVERTERS, SWITCHES AND CIRCUIT BREAKERS
• CREW HABITABILITY	65-75	• EVA EQUIP, FOOD STORAGE AND PREPARATION, AND CLOTHING, AIRLOCK
• PROPULSION - RCS	70-80	• FUEL AND OXIDIZER TANKS, THRUSTERS, VALVES, AND PRESSURIZATION SYSTEM
• GUIDANCE AND CONTROL	40-50	• RCS DRIVER ELECTRONICS, HAND CONTROLLERS AND CONTROLS/DISPLAYS
• DATA MANAGEMENT AND COMMUNICATION	75-80	• COMPUTER, MDM'S, ANTENNA, RECEIVERS, TV CAMERAS, AND SIGNAL CONDITIONERS
• RMS	50	• TECHNOLOGY

Figure 5-2. Orbiter Hardware Summary for SCB Applications

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SUBSYSTEM	SELECTIONS
STRUCTURAL MECHANICAL	• PHASE B BERTHING MECHANISM • ORBITER D-HATCH DOCKING MECHANISM • 53 FT MAX LENGTH PRESSURE SHELL
ECLSS	• CLOSED WATER – OPEN O_2 WITH HS-C CO_2 CONTROL • O_2 RECOVERY – DESIGN FOR RETROFIT
ELECTRIC POWER	• SOLAR ARRAY POWER SOURCE • BATTERIES FOR ENERGY STORAGE
CREW HABITABILITY	• WHOLE BODY WASHING-ORBITER SPONGE BATH • FOOD – ORBITER TYPE FREEZE DRIED, DEHYDRATED, THERMALLY STABILIZED
PROPULSION – RCS	• THRUSTERS – ORBITER 25 LBF VERNIER THRUSTERS • COMPONENTS/PROPELLANT (MMH & N_2O_4), ORBITER TANKS, VALVES AND CNTRLS
GUIDANCE AND CONTROL	• IMU's, STAR TRACKERS AND HORIZON SENSORS • INTERFACES WITH DATA MANAGEMENT SYSTEM IN ORBITER OR CS • ATTITUDE CONTROL AND ORBIT KEEPING – RCS
DATA MANAGEMENT AND COMMUNICATION	• DISTRIBUTED DATA PROCESSING – ORBITER • STANDARD TDRSS COMPATIBLE COMMUNICATIONS – ORBITER
CRANE	• 7–8 DEGREES OF FREEDOM – 2 ARMS/35M REACH • TURRET CONTROLLED/DIRECT VISIBILITY

Figure 5-3. Key SCB Subsystem Selections

The structural/mechanical subsystem uses the Phase-B berthing mechanism which could include the capability of also serving as a docking port. However, the currently planned Orbiter docking mechanism uses existing designs and technology which is not compatible with low berthing latching loads and compliance requirements. Therefore, a basic transition tunnel with the SCB berthing mechanism and the Orbiter docking mechanism has been included.

A closed-water and open 0_2 ECLSS design was selected for initial versions of the SCB due to its lower initial cost. A requirement to incorporate the capability to retrofit for closed oxygen is included in the design to reduce logistics support later in the program.

Solar arrays for power source and batteries for energy storage were selected at this time for the electrical power system on the basis of a proven technology and, therefore, minimum program risk.

Crew habitability provisions are compatible with the comparatively austere construction shack philosophy. Sponge body cleansing and Orbiter-type food are selected. Maximum use is made of existing Orbiter components such as clothing, food, personal hygiene facilities, and EVA equipment.

The reaction control and drag make-up propulsion subsystem makes significant use of existing Orbiter hardware which will save significant DDT&E costs. This bipropellant concept is not as contaminant-free as an advanced H_2-0_2 system but represents existing and proven technology.

The IMU in the guidance and control subsystem provides the basic attitude reference for control logic. It is supported by star tracker reference and the navigation ephemeris for accuracy update for a wide variety of desired orbital reference orientations. This is preferred for its field of view requirements when compared to the four quadrant horizon sensor system and potential interfence of the large space construction elements.

5.1.4 Module Design Requirements

The integration of the SCB objective elements and crew support requirements resulted in module functional design requirements that produced a Space Construction Module, Construction Shack Module, Power Module, and Space Processing Development Facility module which are the primary building blocks of a space construction base.

The Space Construction Module requirements are:

- Supervision and scheduling of construction projects and resources
- Material handling and module/pallet berthing
- Testing of objective elements components and complete assemblies
- Maintenance and storage of EVA crew equipment and construction tools
- Secondary emergency refuge area

The Space Construction Shack Module requirements are:

- Supplant the Orbiter (Shuttle-tended) mode subsystem support crew/SCB, etc.
  - Accommodation of seven-man crew in continuous operation mode
  - Storage of consumables for crew up to 60 to 90 days
  - EVA crew support and airlock
  - Control of SCB subsystems and orbital operations
- Additional module/pallet berthing and support
- Provide two emergency refuge areas

The Space Processing Development Facility module (mission hardware) requirements are:

- Support of manned test projects with one to two crews for up to 90 days
- Accommodation of bio-material processing and containerless processing of ultrapure material and shaped crystals
- Provison of environmental isolation for contamination critical and toxic materials

- Bus power of 15 kW and related heat rejection
- Capability for maintenance, modification and changeout of equipment on orbit

The Power Module requirements are:

- Bus power - 38 kW continuous at the bus
- Heat rejection - internal and excess over Orbiter capability of approximately 24 kW
- Communication/data management-telemetry in free-flying mode
- Attitude control

5.2 SUPPORT MODULES – CONFIGURATION DESIGN

Configurations were developed based on definition of internal and external subsystem design drivers. Internal operational design drivers were defined for crew shirtsleeve, EVA preparation activities, and supporting subsystem requirements.

Outboard configuration development was approached in a similar manner. The operations and functions which placed design drivers on the outboard SCB configuration were also identified. These included, for example, Orbiter docking corridor, Orbiter docking - normal and emergency locations, and construction working envelopes.

These preliminary analysis results assured the development of SCB configurations which were responsive to and consistent with the functional and operational requirements of all program aspects.

System-level guidelines were established early in the study and continually refined or modified as the study program definition and direction developed. In addition to these guidelines, Space Construction Base design guidelines and criteria were prepared by NASA for SCB and mission hardware conceptual analysis and design at the detail level. These also reflected the shift in study program definition occurring during the progress of the study and the lessons learned as related to the key issues addressed during each of the three study parts.

The study system-level guidelines reflect the basic philosophy of an SCB concept based on the low-cost reduced-complexity Construction Shack approach. This concept is in contrast to the Space Station concepts defined in earlier Phase B studies which were fully autonomous stations (i. e. , never Shuttle-tended), primarily scientific R&D oriented, and had fully optimized subsystems and components. With regard to module conceptual design, the study system-level guideline key drivers are the following: Minimum crew support will be provided for SCB operations consistent with safety and performance requirements; relaxed subsystem operational performance and tolerances will be employed; fail operational/fail-safe criteria will only apply to critical subsystems. The result of these guidelines, particularly the latter two, was to allow the use of available hardware and technology, predominantly from the Orbiter program. This may not be optimum for the performance of a given function; however, hardware capability will be sufficiently close to allow its use. This is also reflected in the following lower-level criteria: subsystems will maximize the application of off-the-shelf hardware; and replacement/maintenance requirements will be consistent with the off-the-shelf hardware designs. Therefore, operational and support requirements will be determined by the hardware rather than by a common set of pre-established rules. A certain amount of flexibility in selecting hardware and scheduling its maintenance will, therefore, be needed.

In addition, all modules and mission hardware elements will be compatible with Shuttle-tended operations and possess the necessary capability for growth to continuously manned SCB configurations. Minimum growth interface problems will occur if the equipment provided for SCB subsystems is identical with that employed by the Orbiter. To successfully achieve this, selected Orbiter hardware must be compatible with the evolving nature of the SCB. The design concepts described in the following sections are based on these criteria.

5.2.1 Space Construction Module

Based upon the requirements and characteristics of the mission hardware, SCM elements were defined as illustrated by Table 5-1. As shown, they are grouped into the four major categories of: crane system, construction control or supervision, construction/test support, and crew support system.

Constituents of the crane system include the movable EVA work platform or cherry picker, end effectors, crane arm controllers, video display for arm-mounted cameras, and function keyboard, processes and status/mode panel for control of automatic operations. Displays and manual controls would move with the crane operator so as to be accessible and independent of crane turret/arm positions.

Table 5-1

SPACE CONSTRUCTION MODULE ELEMENTS

Crane Systems	Construction/Test Support
• Cherry picker/remote control	• Workbench and laminar flow box
• Crane and end effectors	• Test control console
• Crane controller	• Component testers
• CRT display system	• Pallet berthing ports
• Function keyboard	• Floodlight control panel
• Crane miniprocessor	• Tool/parts cabinets
• Crane status mode panel	Crew Support Systems
Construction Control	• DCM battery chargers and panel
• Microfilm retrieval unit	• Suit drying area
• Hard copy printer	• Audio terminal units
• Construction status panel	• Caution and warning status display and annunciator
• Data acquisitions and display	• Emergency pallet (retrofit)

Construction control would be aided by access to schedules, procedures, and indexes within the SCB data storage archives supplemented by a microfilm retrieval unit and printer providing hard copy data such as equipment schematics, construction layouts, and procedural details to be produced. An inventory control unit would automatically track tool and spares availability.

To support equipment repair and test, workbench outfitted with repair, test units, and enclosure hood to prevent atmosphere contamination is provided. Other equipment related to construction support from a centralized location is also included as listed.

To support personnel within the SCM, standard SCB assemblies such as audio terminal units and Caution and Warning (C&W) displays are carried. Due to the use of the Orbiter two-man standard airlock, suit drying, display and control module batteries maintenance, and primary life support system maintenance will be performed in the SCM.

The selected configuration of the SCM of those considered during the study, shown in Figure 5-4, is configured for the exclusive purpose of supporting construction. The module is 9.5 m (31.25 ft) long with a maximum external diameter of 4.42 m (174 in.) and an internal pressure shell diameter of 4.26 m (168 in.). The module depends entirely on external sources for the operational subsystems support and resources necessary for its operation. These resources may be supplied from either the Orbiter, Construction Shack, Power Module or power platform depending upon the SCB configuration (i.e., Shuttle-tended or continuously manned). The SCM is configured to provide adequate but not excessive facilities for construction and test support. Space is allocated for retrofit of crew emergency provisions,

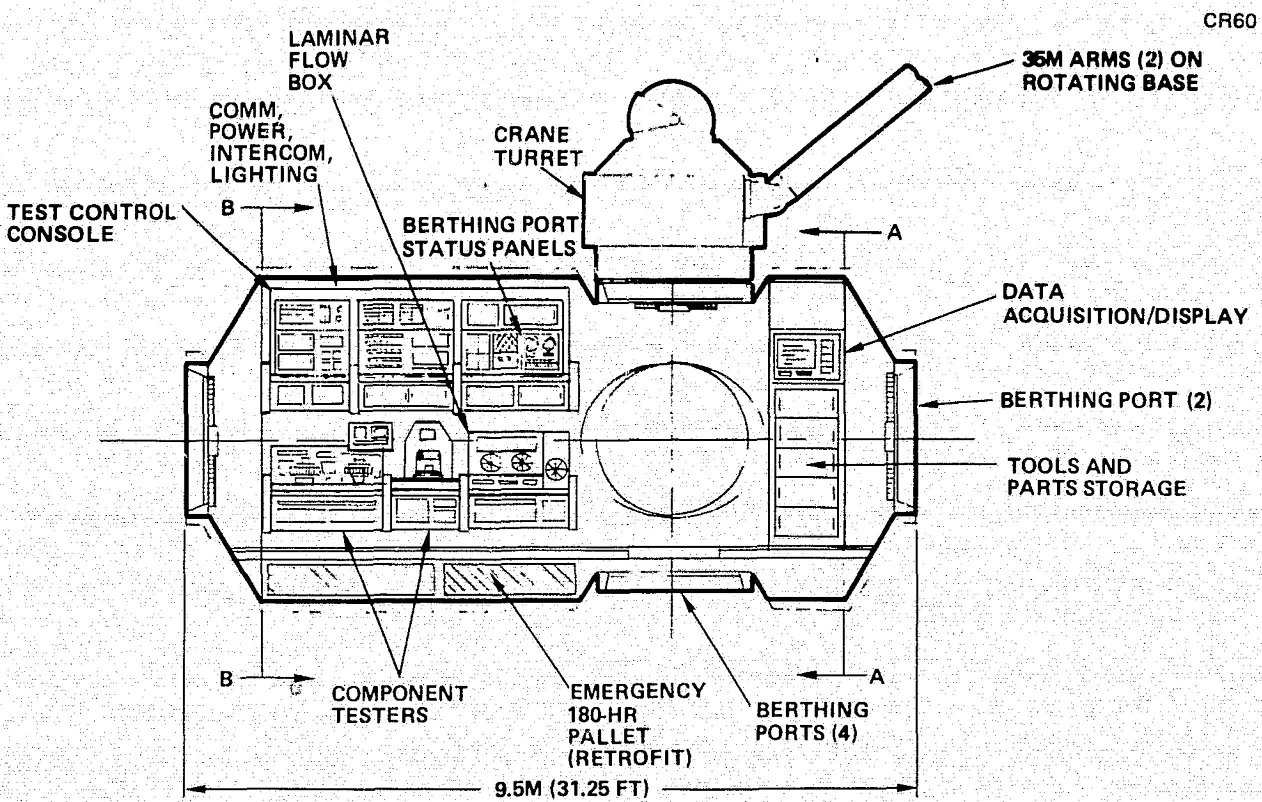

Figure 5-4. Space Construction Module Concept

thus enabling the module to provide a retreat area in the continuously manned SCB mode.

The module contains five basic facilities: (1) construction control, (2) test control, (3) EVA equipment support, (4) module subsystems, and (5) tools and part storage. The basic facilities include microfilm storage and retrieval unit, printer, schedule status, extravehicular mobility unit (EMU) charging and replenishment equipment, component testers, parts inventory control, status panels, workbench facilities and exterior/interior lighting. The internal arrangement is dominated by the four radial berthing ports. Each port is passive, containing only the structural ring and alignment guides used to berth construction material pallets. Also incorporated are two axial berthing ports, one active and one passive, to provide appropriate interface with other SCB elements such as the construction shack and the strongback. The addition of a kit to the passive port will make it compatible with the active port, making universal berthing possible. The launch mass of the SCM is 13,518 kg (29,800 lb).

5.2.2 Construction Shack Module Elements

The functional elements of the construction shack have been divided into crew systems, EVA systems, SCB control systems, and SCB passive systems. Since the Construction Shack replaces the Orbiter in the transition to continuously manned operations (with expanded on-orbit duration capability), all conventional subsystems are represented in Table 5-2.

Crew systems, while comparatively austere, are adequate to support the seven-man crew at an acceptable comfort level. The control systems provide all resources and perform all control operations with the exception of power generation, storage, and primary regulation. The communications components (such as transmitters, receivers, amplifiers, and signal processors) and the data management assemblies (such as computers, input/output (I/O) units, multiplexers/demultiplexers and certain display and control equipments) have been included in the electronics racks. Also resident in those racks would be elements of the attitude control system such as the guidance and navigation (G&N) preprocessor.

Table 5-2

CONSTRUCTION SHACK MODULE ELEMENTS

Crew Systems	EVA Systems
• Seven-crew quarters	• Airlock - two-man
• Food management assembly	• EVA suits
• Waste management assembly	• Personal rescue
• ECLS assemblies	• Manned maneuvering unit
SCB Support Systems	**SCB Passive Systems**
• Thermal control assembly	• Consumables storage
• Data management	• View ports
• S/Ku band equipment	• Berthing ports
• Ku-band antenna assembly	• Lighting system
• Attitude control assembly	
• SCB control station	
• Power distribution system	
• Status/control panels	
• Reaction control pod	

The EVA subsystem employs a standard Orbiter two-man airlock in order to minimize costs. Other elements in this category are also available from the STS program. The passive system include miscellaneous items such as internal lighting and logistics storage. A significant change to modules of this type is the addition of consumables storage for the SCB. This is in lieu of a logistics module, thus reducing the SCB size.

The Construction Shack (CS), as shown in Figure 5-5, is 16.15m (53 ft) long and has a maximum cylindrical diameter of 4.42 m (174 in.) and an internal pressure shell diameter of 4.26 m (168 in.). The CS has two axial berthing ports, one active and one passive, and four radial passive berthing ports. There are two retractable Ku-band antennas spaced 180 degrees apart and indexed to minimize interference from berthed modules. These may be moved to the strongback, if there is excessive interference.

The interior of the CS represents an austere low-cost approach for crew quarters and facilities without compromising crew safety or performance. Individual crew quarters for the seven-man crew total approximately 2.5 m^3

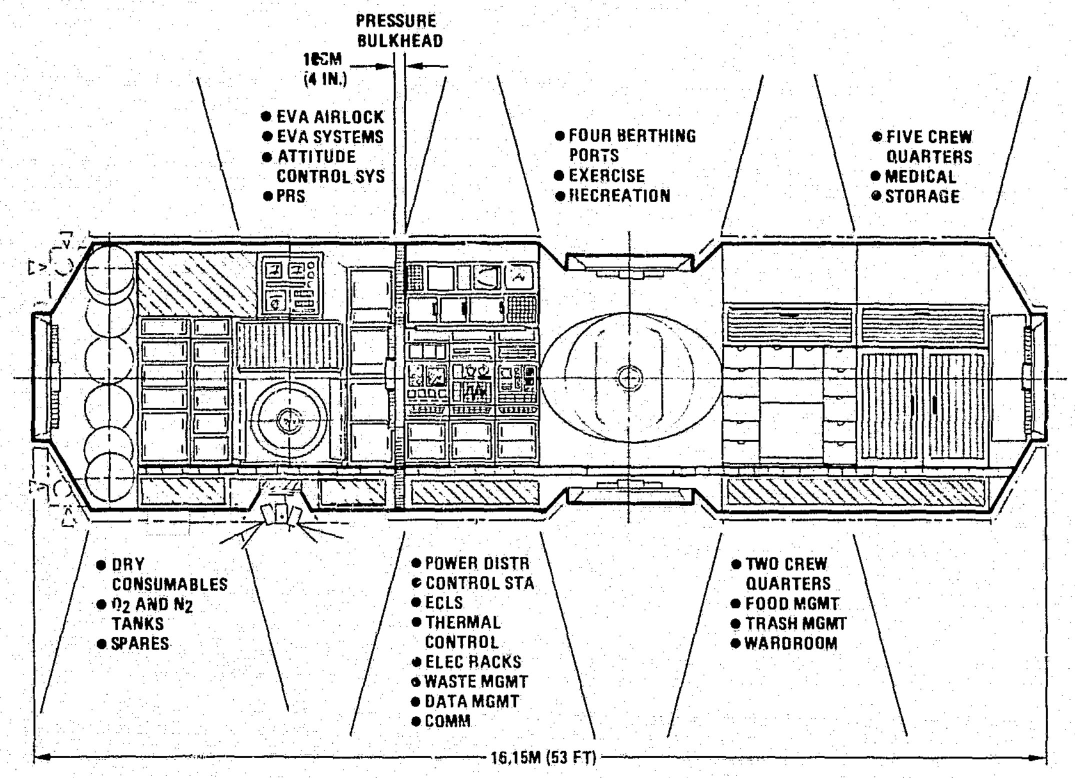

Figure 5-5. Construction Shack Concept

(90 ft^3) for each crew member. Each compartment contains a bunk, personal effects storage provisions, and a 0.3 m (12 in.) diameter viewport. Each crew quarter has accordian-type doors which can be latched open to expand the spaciousness of the compartment if desired. Other functions within the module besides crew habitability include: (1) primary environmental control and life support, (2) SCB control, (3) food, trash and waste management, (4) hygiene and medical, (5) EVA systems and support, (6) consumable storage, (7) communications, and (8) wardroom and exercise area.

Emergency provisions include a pressure bulkhead that separates the module into two pressurizable volumes, as well as caution/warning annunciators, and batteries to provide emergency energy. The consumable-storage area has been incorporated to support the seven-man crew for up to 90 days. This approach permits each Orbiter flight to transport consumables within Orbiter available volume, thus eliminating the need for a dedicated logistics module.

Operational EVA systems are incorporated in the CS and employ a standard Orbiter two-man airlock with a 1 m diameter EVA hatch. Pre- and post-EVA

provisions are located adjacent to the airlock and separated from the habitability section by the pressure bulkhead. The launch mass of the CS is 10,256 kg (22,600 lb).

5.2.3 Power Module Concept

For purposes of this study, emphasis was placed upon identifying additional operational requirements associated with support of an SCB. Power levels developed in conjunction with various program schedules indicated that 25 kW to 38 kW (average bus) was adequate — the lower power level resulting in series rather than parallel operations.

A 38 kW Power Module concept which utilizes eight of the baseline solar electrical propulsion system (SEPS) arrays is shown in Figure 5-6. Four arrays are mounted on each of two 16-meter long support beams. A single launch packaging arrangement has been developed.

In orbit, the power module launch package is rotated out of the cargo bay on the payload installation and development aid system (PIDAS) and berthed at the docking module with the remote manipulator system (RMS). The RMS is then used to mate the mounting flange at the center of each of the two support beams with the gimbal fitting on the outboard end of each of the two telescoped cylinders. The telescoped sections are then extended and the flanges on the inboard ends secured.

The Power Module contains a limited communications-navigation system and control moment gyros (CMGs) for free-flight between Orbiter visits. The eight SEPS arrays provide 38 kW average power at the beginning of life. The Power Module contains the power conditioning equipment and batteries required to make it an autonomous power source.

A 4.4-meter wide, 16-meter long radiator panel is mounted along each of the two array support beams. The radiator panels are hinged to fit within the cargo bay clearance envelope. Mounted outboard of the gimbals and normal to the plane of the arrays, as shown in the figure, the radiator panel surfaces are always parallel to the sun line to maximize heat rejection.

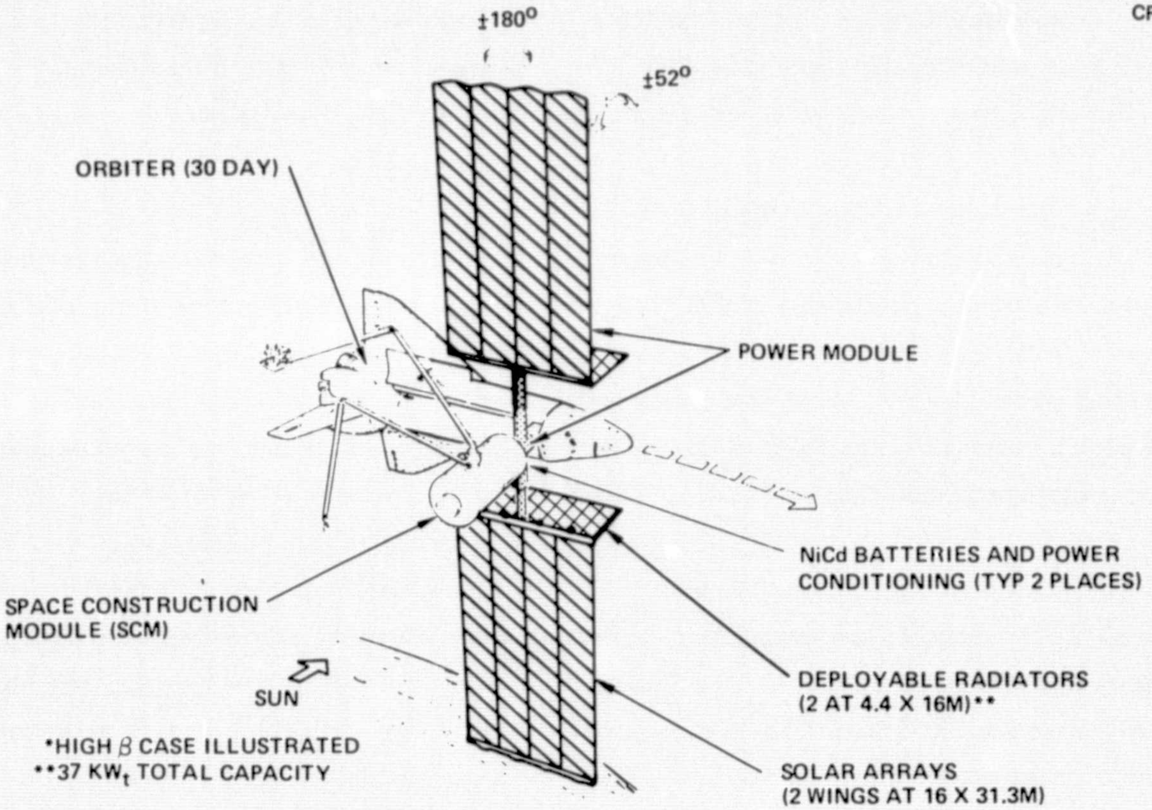

Figure 5-6. Power Module (38 KWe Average)*

5.3 SUBSYSTEM DESCRIPTIONS

The approach to the design of the low cost Construction Shack module began at the subsystem level. Various concepts for each subsystem were developed and compared for use in the CS module. A discussion of these trades and a brief description of the selected subsystem designs are included in this section. Detailed descriptions of this effort are contained in the appendices.

5.3.1 Concept Approach and Key Guidelines

The low-cost Construction Shack concept is an outgrowth of an intermittently manned Shuttle-tended configuration. The Construction Shack concept is characterized as a system using off-the-shelf Orbiter subsystems hardware. Design Guidelines and Criteria for the Low Cost Space Construction Base are detailed in Reference JSC-11867, Revision A.

5.3.2 Subsystem Concepts and Trades

The Part 3 subsystem design effort consisted of performing trades and analyses leading to the selection of preferred concepts and then definition of the subsystem in sufficient detail to support the costing task and detailed SCB defini-

tion. Subsystems were defined in terms of block diagrams, equipment lists, and performance and physical characteristics. These activities considered interactions with other subsystems and SCB elements.

5.3.2.1 Structural/Mechanical

The structural and mechanical subsystem consists of the primary pressure enclosures of the modules, the living and working quarters, mounting fixtures, storage facilities, structure for environmental protection, and docking and berthing provisions. Each item associated with the structural/mechanical subsystem was addressed to determine satisfaction of minimum requirements for the Construction Shack Module and the Space Construction Module.

For the Construction Shack Module, it was assessed that approximately 5,300 ft^3 was necessary to accommodate a maximum of seven crewmen and equipment. This volume included a free volume of about 200 ft^3 per man, which is judged to be adequate based on experimental data associated with mission duration and cabin space confinements.

The module necessitated a pressurized structure suitable for living quarters plus a separate area to be used for refuge in case of emergencies. An airlock was incorporated into the design to accommodate two suited men.

Berthing structure and the associated mechanical subsystems comprised almost 1,000 ft^3 of the module.

In summary, the minimum module requirements for the Construction Shack were accommodated by a pressurized structured 16.15M (53 ft) in length.

A similar approach was used to design the structural arrangement in the Space Construction Module. The two modules utilize a common primary structural design with different internal arrangements, secondary structure, furnishings and subsystem equipment.

The primary structure of the modules' integrally machined internal waffle construction is fabricated from 1-inch thick 2219-T851 aluminum plate. Hatches provide crewmen passage from one habitable volume to the other. When closed, these hatches provide a pressure seal interface for the structural subsystem. The selected hatch is a 70 x 46 inch rectangular hatch and is

used at all berthing ports and internal bulkheads. The SCB has been configured to have adequate windows arranged to allow the crew to control vehicle attitude by reference to the external scene, enable visual contact with construction activity, visual contact with construction activity, visual contact during rendezvous and docking, berthing operations, EVA activity, and to observe motion of the power platform. A standard 14-inch clear diameter viewing window is used.

Each of the SCB modules incorporate berthing assemblies that provide for the impact, capture, mating, and attaching various modules into a functional SCB. Each module berthing port contains an active or passive ring-cone assembly, a pressure hatch assembly, and utilities interface assembly. All linkage and hatch mechanisms and utilities are completely shirtsleeve-accessible for operation, maintenance and replacement.

5.3.2.2 Crew Habitability

Based on SCB design guidelines, an updated list of all Orbiter assemblies and components relevant to the Crew and Habitability subsystem was compiled and the list then examined and evaluated for potential SCB application. This effort culminated with identification and selection of potential Orbiter subsystem applications to a SCB.

It was concluded that of the 27 assemblies available from the Orbiter, 22 (59 percent) were directly applicable for incorporation into the SCB, 7 (19 percent) were applicable with modification required, 3 (8 percent) were not applicable, and 5 assemblies (14 percent) were considered but it was determined that currently they were not sufficiently defined to make a valid judgment.

Among the findings was the fact that the Orbiter EVA subsystems would require significant modification to accommodate the two-shift EVA operations of the Space Construction Base. The modifications would primarily consist of making provisions for airlock pumpdown capability and relocating the recharge and don-doff stations from inside the airlock to the interior of the Space Construction Module. Also, assemblies for recreation, exercise, and medical care applicable to SCB must be developed. It is important to

note that the comparatively austere Crew Habitability subsystem derived from maximum use of Orbiter assemblies and equipment will entail acceptance of some potential reduction of crew efficiency. Details of Crew and Habitability subsystem concepts and their relationship to Orbiter equipment can be found in Appendix 6.

5.3.2.3 Environmental Control and Life Support

The selected ECLSS design was a result of concept selection by cost tradeoffs and integration of these selections into the SCB using efficient operation and interface with other subsystems and vehicle elements as the primary criteria. Active thermal control design determined the available integral radiator areas and performance, deployable radiator options, a recommended approach based on projected heat rejection requirements. Details of these tradeoffs can be found in Appendix 10.

An open oxygen, closed water environmental control/life support system (ECLSS) concept was selected, driven primarily by the guidelines of low initial cost and maximum use of off-the-shelf hardware, see Figure 5-7.

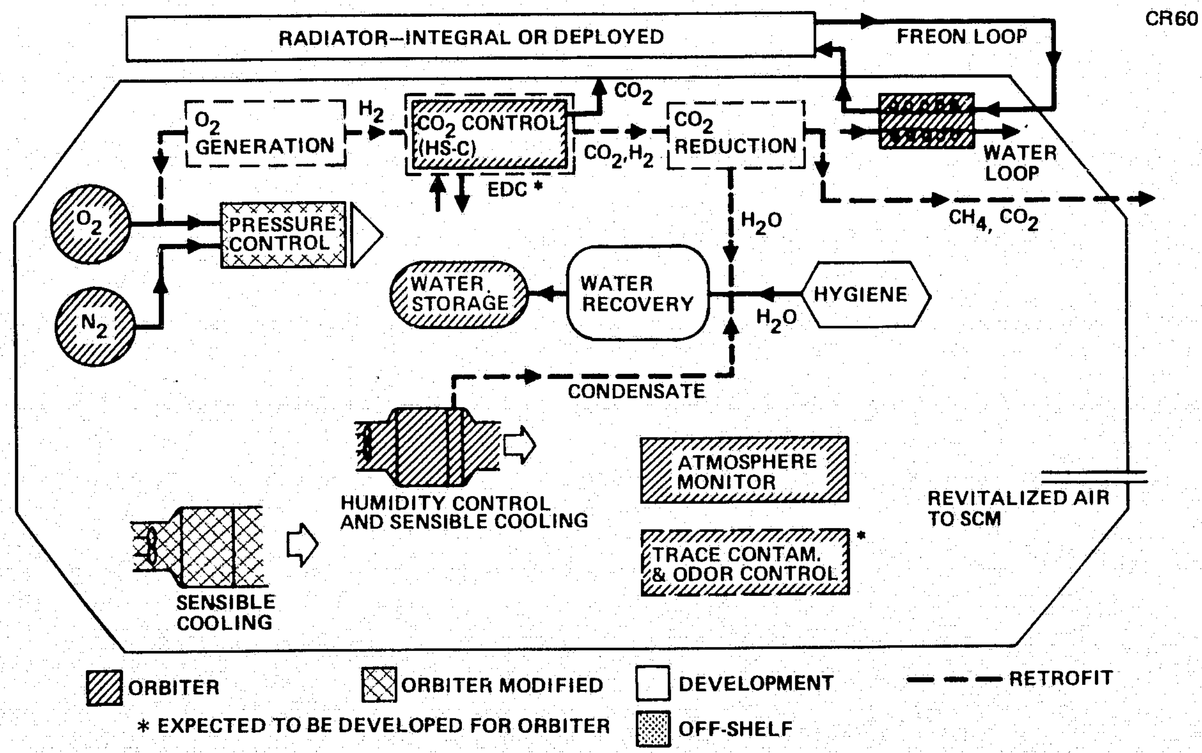

Figure 5-7. SCB ECLSS Block Diagram – Orbiter Hardware Application to Construction Shack

High-pressure gas supplies the makeup oxygen for crew metabolic use and leakage and nitrogen for leakage makeup. Carbon dioxide is controlled by a vacuum dump, solid amine system designated HS-C. This unit also controls humidity by removal and vacuum dump.

Air temperature control is obtained by the use of modified Orbiter humidity control heat exchangers. The humidity control capability is retained on one heat exchanger in the Construction Shack for later use when a closed O_2 concept is retrofitted. This advanced system will use the Regenerative Life Support Evaluation (RLSE) concepts for closing the oxygen loop.

Water is recovered from all water sources except fecal water. The selected concept uses a vapor compression distillation concept with multifiltration for odor and bacteria control. Iodine maintains potable water sterility during storage. Studies have shown that about 40 to 50 percent of the ECLSS can be Orbiter-derived hardware. See Appendix 10 for detailed ECLSS descriptions.

A thermal analysis of radiators showed that the integral radiators have excess capacity for removing the anticipated heat rejection requirements for the CS and SCM. The analysis assumed a zero beta angle, a radiator fluid flow away from the earth and a conventional Z-93 coating in a degraded condition ($\alpha/\epsilon = 0.39$). Deployable (flat plate) radiators were also analyzed as an alternative or supplement to the integral radiators. The deployable configurations have excellent performance because of two-sided heat rejection and more favorable selection of orientation. Although integral radiators were baselined, careful consideration must be given to deployable radiators because they can provide high performance margins and could reduce cost, largely due to integration costs for the integral radiator.

The Space Processing Module heat rejection appears ample if dual low-temperature/high-temperature radiators are used on the module. This approach requires less radiator area and has the advantage of selecting a high-temperature radiator fluid which will not decompose or poses high operating pressures at temperatures envisioned for cooling space processing payloads.

Analysis of the Power Module deployable radiator shows the feasibility of a simple radiator design which can reject all heat energy produced by the Power Module. This approach would increase the autonomy of the Power Module, eliminating or reducing heat rejection required of elements being serviced by the Power Module.

5.3.2.4 Data Management

The data management subsystem (Figure 5-8) will employ distributed preprocessors in order to provide an efficient system which will operate in conjunction with either the Orbiter or Construction Shack file management and memory system. The preprocessors are standalone units with adequate memory for identified modes or tasks. In addition to power, G&N and crane data processing, the pulse code modulation (PCM) and display electronics assemblies may be considered in this category since they also contain limited memory and control components.

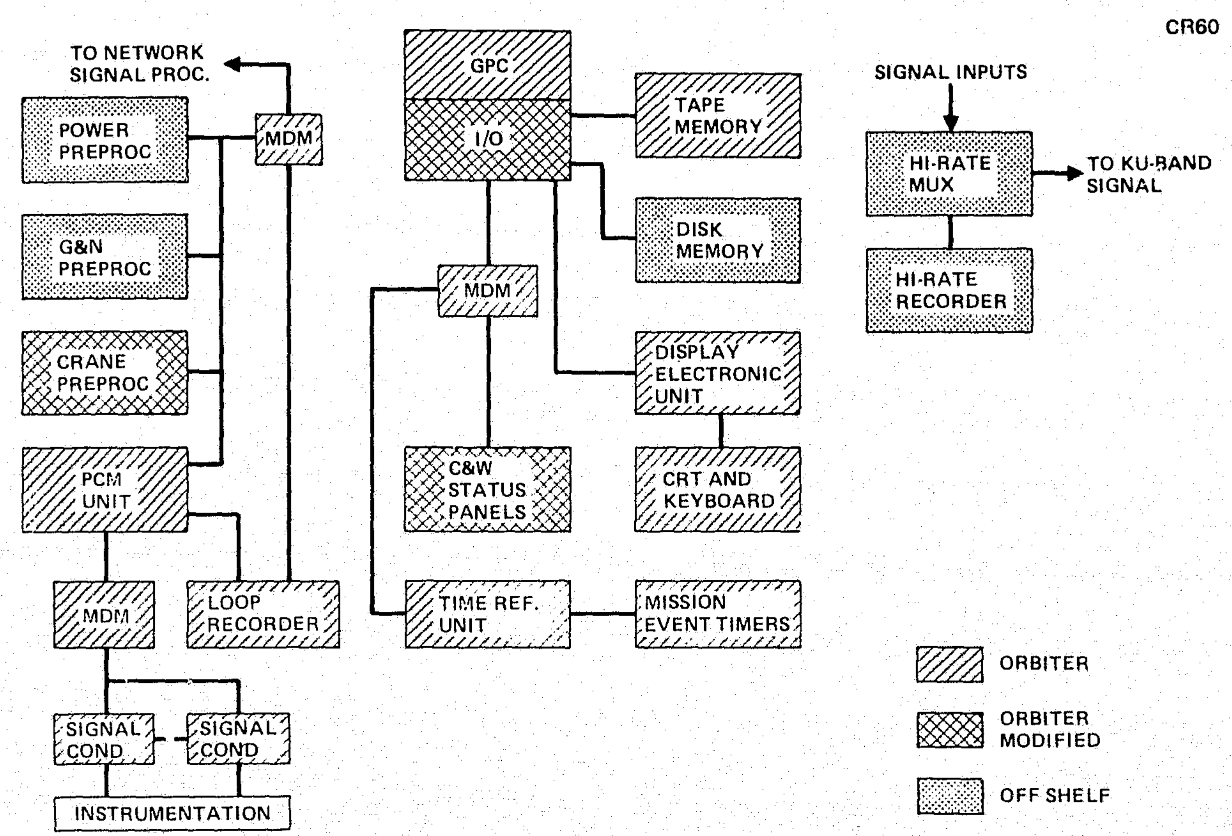

Figure 5-8. SCB Data Management Block Diagram, Orbiter Hardware Application

The general-purpose computer is a standard Orbiter unit which is primarily used for preprocessor program storage and retrieval. The I/O has been modified in order to accept the off-the-shelf disk memory system, which provides quicker and more reliable program or data transfer than the tape system. All interfaces external to the computer system are via multiplexer-demultiplexer (MDM), resulting in minimum integration problems for Orbiter equipment.

In addition to the Orbiter equipment two units of Spacelab hardware, the High Rate Multiplexer and the High-Rate Recorder are employed. However, these units are primarily for use in support of space processing and could be installed on a retrofit basis.

Fault detection will be performed by instrumentation, signal conditioning, the PCM unit and the computer. Since data will not be continuously processed, the loop recorder is needed to allow complete malfunction histories to be obtained. To preserve the data in the event RF transfer to the ground is not available at the particular time required, a standard recorder will also be required. The C&W system will employ redundant multiplexed data streams in lieu of the hard line/multiplex system currently used on the Orbiter. Some simplification of the system should result at the cost of operating the standby general purpose computer (GPC) at a low level of activity. Some minor modifications of the C&W status panels will be required. See Appendix 6 for detailed data management descriptions.

5.3.2.5 Communications Subsystem

Communications will be handled by the Orbiter during the Shuttle-tended mission phases. During free-flying periods only telemetry and command control is required and this can be handled by the Power Module. With the launch of the continuously manned Construction Shack, communications will be transferred to this module.

The degree to which Orbiter communications equipment may be employed by the Space Construction Base is illustrated in Figure 5-9. During early mission phases, or those without without high-data rate transfer requirements, the S-band phase modulation system may be employed for telemetry and

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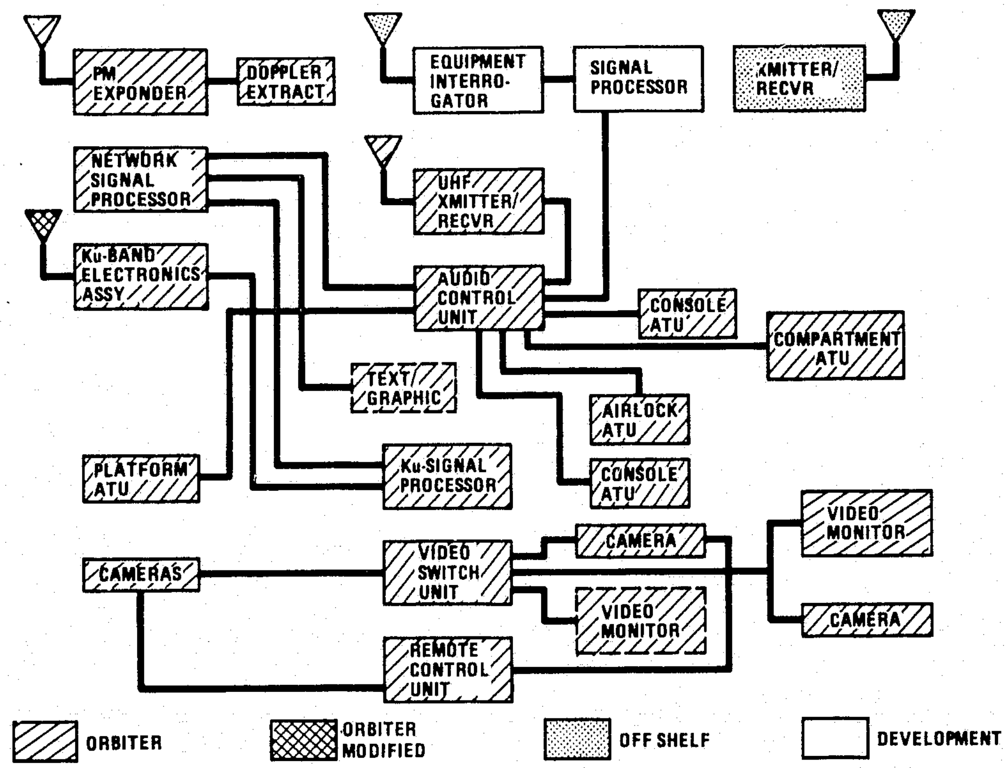

Figure 5-9. SCB Communication Block Diagram, Orbiter Hardware Application

voice communications as well as tracking applications. As part of the voice system, the audio control unit and audio terminal unit (also used on Spacelab) as well as the UHF transmitter and receiver for EVA operations are usable without modification.

For high rate data transfer to the ground via tracking and data relay satellite (TDRS), the Ku-band antenna system and electronic assemblies may be employed, although some extension of the booms now used may be necessary to reduce shadowing or multipath and to obtain a clear field of view. Internal communications requiring large bandwidths, such as closed circuit TV, may also use Orbiter hardware such as the video switch, remote control unit, cameras, and monitors. However, some penalty is involved since monitors are black-and-white rather than color and raster size at 7 by 10 inches appears to be small for continuous viewing. This equipment may be augmented by high-rate multiplexing components (not shown in the figure) available from Spacelab.

A lack of available equipment is noted only in regard to remote simultaneous control of construction equipment, satellites, or other vehicles. Since similar Orbiter/payload operations will have been conducted for some time prior to the advent of the SCB, even these components may be usable with only minor modifications. See Appendix 6 for detailed communication subsystem descriptions.

5.3.2.6 Guidance, Navigation and Control Subsystem

A block diagram of the Guidance Navigation and Control Subsystem (GN&CS) is given in Figure 5-10, illustrating the subsystem elements and the attendant subsystems necessary to complete the flight control function. The subsystem hardware elements are categorized according to their source derivation. The star trackers can be applied directly from the Orbiter, and other elements such as the Reaction Control System (RCS) drivers and displays and controls can be derivatives of Orbiter equipment. The preprocessor horizon sensors and the inertia measuring unit (IMU) can be applied to

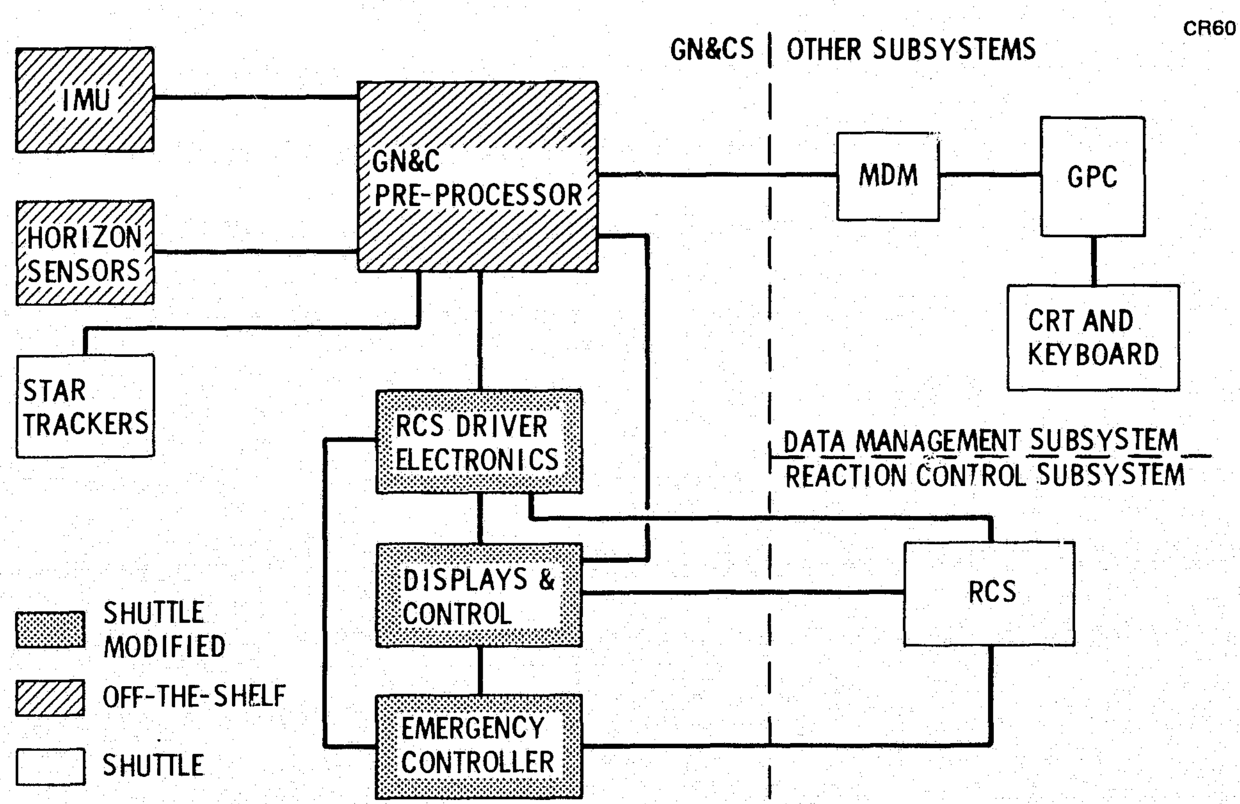

Figure 5-10. Guidance, Navigation and Control Subsystem Block Diagram, Available Hardware Applications

the subsystems from available off-the-shelf units. The requirements derived for SCB GN&C are summarized in Table 5-3, and indicate no significant technology advancements.

The basic attitude sensor is an internally redundant, strapdown IMU of medium, rather than high, precision quality. The IMU, for all the configurations and orientations involved, must be updated by periodic star fixes based on ephemeris update navigation and a star catalog which are located in the general purpose computer of the Data Management Subsystem. The application of modern filter theory to the gyro update data can assist in calibration of the IMU gyro drifts. The horizon sensors combine with the

Table 5-3

GUIDANCE, NAVIGATION AND CONTROL SUBSYSTEM REQUIREMENTS

Functions	Requirements Range
• Flight Modes	Local vertical Local vertical/princ. axes Orbit ref. inertial Inertial hold Manual
• Attitude Reference	
- Orbit	± 0.25 deg (1σ)
- Inertial	Above ± 0.50 deg/hr (1σ)
• Actuation	Mass exp. ~111N (25 lb) thrust
• Translation	Mass expulsion
• Deadbands	
- Attitude - Fine	± 0.25 deg
- Attitude - Coarse	Adj. to $\pm$ deg ($\pm$ deg long term)
- Rate - Long Term	0.001 - 0.002 deg/sec
- Rate - Coarse	TBD
• Slew	0.2 deg/sec nominal
• Navigation	
- Ephemeris	Onboard update (~1160 m)
- Free Modules	TBD
• Displays	Status Mode selection and disp. Maneuver control

IMU to provide an orbital gyrocomposing reference to serve as initial conditions for the stellar inertial system. Signal conditioning read time stabilization logic, and thruster selection logic will be performed in the pre-processor.

Although CMG's were analyzed and found to reduce the amount of RCS propellant by one-half, they were not baselined due to initial development costs. If used, it is expected that they would be an outgrowth of the ATM CMG's with improved bearings and unlimited gimbal freedom. See Appendix 6 for detailed guidance, navigation, and control subsystem descriptions.

5.3.2.7 Reaction Control

The RCS configuration selected for the SCB is a cruciform arrangement of four reaction control pods (RCP's) which are located at the ends of 18 m (60 foot) booms attached to the strongback (see Figure 5-11). Each RCP is autonomous, and resupply is accomplished by exchange of the complete pod using the SCM-mounted crane. Mechanical and electrical interface connections can be effected by remote mechanisms (e.g., electric motor driven) or by EVA personnel.

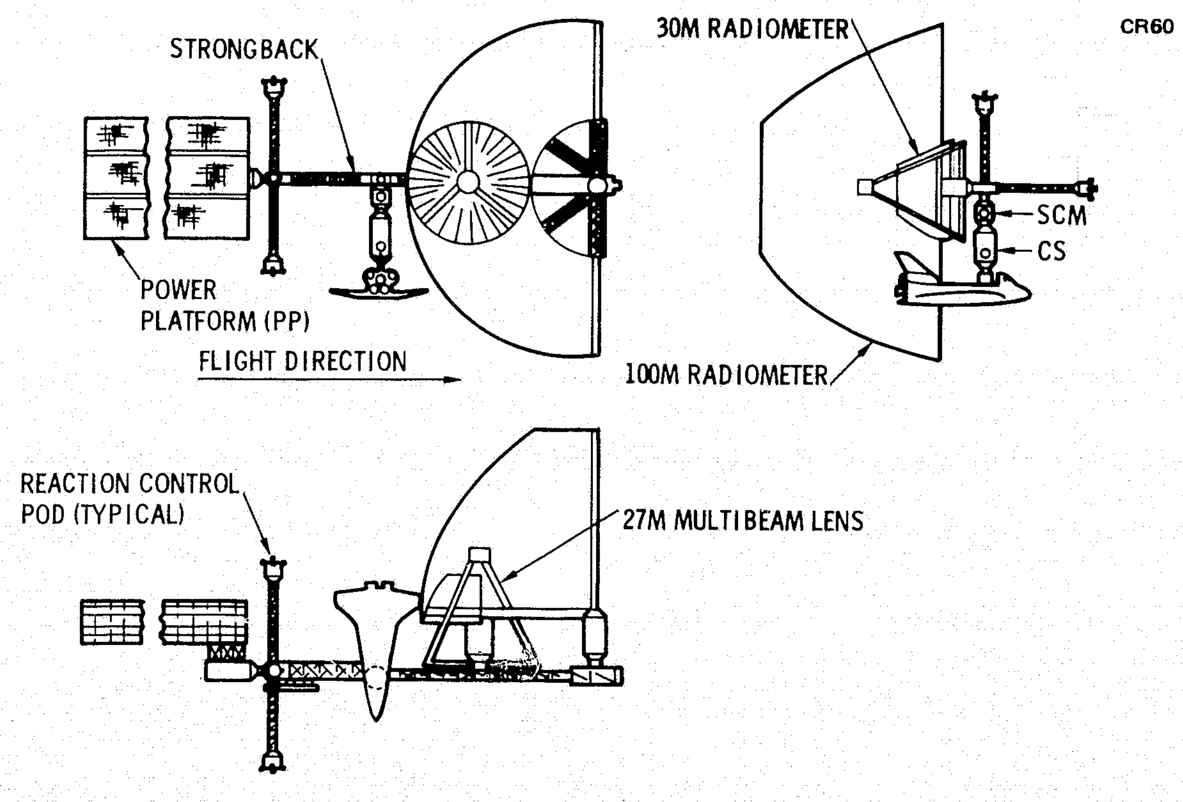

Figure 5-11. SCB Strongback Configuration with Multiple RCS Pods on Strongback Booms

Attitude control, maneuvering and drag makeup considerations indicated a requirement for approximately 1430 kg (3150 lbm) of usable propellant in each RCP for a 90-day resupply cycle. This quantity includes a 40-percent unequal use factor since the pods are not interconnected and analysis of the SCB CG shift indicates that propellants will not be consumed equally.

An RCP design almost entirely assembled from Orbiter RCS/VCS hardware was developed as shown in Figure 5-12. This design uses four Orbiter RCS propellant tanks, since two tanks can only supply approximately 1135 kg (2500 lbm) of propellant, and 1430 kg (3150 lbm) is required for each RCP of the SCB. Therefore, the additional capacity possible with the four tanks can be used to extend resupply time and/or compensate for possible uncertainties in analytically projected requirements. The weights shown are for the basic propulsion hardware and expendables only, and do not include structure, structural supports, thermal control and interface connections.

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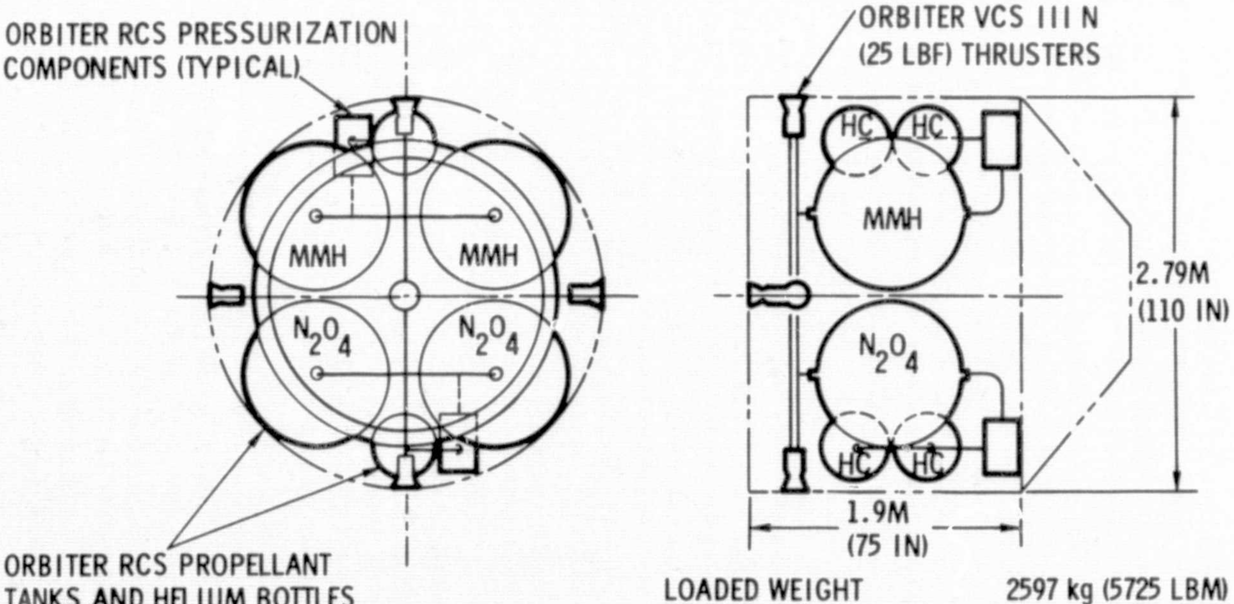

LOADED WEIGHT	2597 kg (5725 LBM)
DRY WEIGHT	281 kg (619 LBM)
USABLE PROPELLANT	2214 kg (4831 LBM)

Figure 5-12. Reaction Control Pod Configuration

Orbital resupply of expendables was considered for the SCB reaction control system but was dropped because of safety, complexity, and development cost considerations. Four boom-mounted configurations were considered (Figure 5-13) for central resupply and individual resupply options. Based on these pro and con considerations, the four-RCP option was selected for the SCB.

It appears feasible to use the Orbiter-derived RCS described above to satisfy the SCB control and drag makeup requirements. However, the impact of the RCS-generated plumes on the sensitive SCB surfaces (i.e., optics radiator, solar cells, etc.) requires additional analyses. See Appendix 6 for detailed reaction control descriptions.

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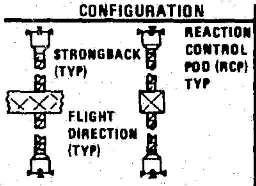
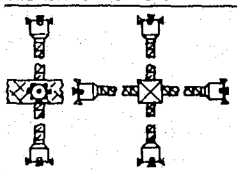
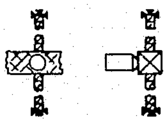
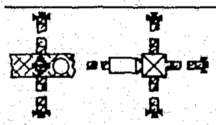
CONFIGURATION	PRO	CON
 TWO REPLACEABLE RCP'S	• ONE RCP OPERABLE WHEN REPLACING OTHER • SHORT FEEDLINES • NO PROPEL LINE DISCONNECT REQUIRED • GROUND C/O AND MAINTENANCE OF ALL HARDWARE	• MAY NOT PROVIDE FULL CONTROL DURING CG EXCURSIONS • PROBABLE UNEQUAL PROPEL USAGE • TWO OPERATIONS REQUIRED TO REPLACE RCP'S • MAY NOT BE ADEQUATE REDUNDANCY IF ONE RCP FAILS
 FOUR REPLACEABLE RCP'S	• THREE RCP'S OPERABLE WHEN REPLACING ANY OTHER • SHORT FEEDLINES • NO PROPEL LINE DISCONNECT REQUIRED • GROUND C/O AND MAINTENANCE OF ALL HARDWARE • GOOD CONTROL DURING CG EXCURSIONS • ADEQUATE REDUNDANCY	• PROBABLE UNEQUAL PROPELLANT USAGE • FOUR OPERATIONS REQUIRED TO REPLACE RCP'S
 CENTRAL REPLACEABLE RCP WITH TWO THRUSTER GROUPS	• UNAFFECTED BY UNEQUAL PROPELLANT USAGE • ONE OPERATION REQUIRED FOR RESUPPLY	• REQUIRES PROPELLANT FEEDLINE CONNECT/DISCONNECT • ORBITAL C/O, MAINT., AND REPLACEMENT OF THRUSTERS • FEEDLINE THERMAL CONTROL BETWEEN TANKS AND THRUSTERS • NO CONTROL CAPABILITY WHEN RESUPPLYING PROPELLANTS • MAY NOT PROVIDE FULL CONTROL DURING CG EXCURSIONS • MAY NOT HAVE ADEQUATE REDUNDANCY
 CENTRAL REPLACEABLE RCP WITH FOUR THRUSTER GROUPS	• UNAFFECTED BY UNEQUAL PROPELLANT USAGE • ONE OPERATION REQUIRED FOR RESUPPLY • GOOD CONTROL DURING CG EXCURSIONS • ADEQUATE REDUNDANCY	• REQUIRES PROPELLANT FEEDLINE CONNECT/DISCONNECT • ORBITAL C/O, MAINT., AND REPLACEMENT OF THRUSTERS • FEEDLINE THERMAL CONTROL BETWEEN TANKS AND THRUSTERS • NO CONTROL CAPABILITY WHEN RESUPPLYING PROPELLANTS

Figure 5-13. Strongback RCS Configuration and Resupply Options

5.3.2.8 Electrical Power Subsystem

The electrical power subsystem (EPS) has been studied extensively in Part 3. It is largely incorporated into two major system modules (the 38 kWe Power Module and the 40-106.6 kWe--depending on the battery capacity installed--power platform). These power systems are discussed in detail in other sections of the report. A detailed description of the Power Module is in Appendix 9; the power platform requirements and designs may be found in Sections 3 and 4.

EPS requirements and guidelines include: (1) a design life of 10 years; (2) the need for a 180-hour crew emergency capability; (3) a solar array power source; and (4) growth shall be accommodated. The 180-hour crew safety requirement is accommodated by a combination of a modular solar array/battery system that provides excellent partial power capability coupled with the emergency ECLSS pallet that has its own silver-zinc battery. Growth is accommodated by the large power platform growth step.

Typical Shuttle equipment that is applicable to the SCB is limited to miscellaneous distribution system items and perhaps the inverters; an open cycle fuel cell system requires excessive weight and logistic cost over a long mission due to fuel resupply requirements. The Shuttle fuel cell is a strong candidate for energy storage, as an alternative to NiCd batteries, in a regenerative mode in conjunction with an H_2O electrolysis unit. The weight of this system will be on the order of 25-30 percent of the weight of the tentatively selected NiCd approach, which is based on the NASA/JSC 110 A-H cell development. NiCd batteries were used as a representative energy storage approach, because of the objective to minimize DDT&E and development risk for the early modules required by the SCB. Further evaluation of regenerative fuel cells and NiH_2 batteries as an alternative to NiCd batteries is required. The batteries and related power conditioning components are located on the Power Module rather than the SCM or Construction Shack, because it is required early in the program before the SCB. This approach is also carried over to the power platform to minimize on-orbit perturbations to the SCM and Construction Shack.

5.4 SPACE CONSTRUCTION BASE CONFIGURATIONS

A subsystem approach was also used to identify key design drivers for the external configurations of the SCB. The approach and a discussion of these key factors in the design are given in this section.

5.4.1 Concept Approach and Key Guidelines

The design definition of SCB configurations in Part 3 utilized the data base for both subsystem and SCB concepts developed in Part 2. These were updated to be responsive to the revised mission objectives and requirements which evolved in Part 3. Primary changes in these areas which had a direct influence on the SCB configurations included the following:

A. Minimum number of modules on the SCB - This approach for minimizing the program costs was based on simplifying the standard (i.e., Phase B Space Station Studies) concepts by combining functions within a smaller number of individual modules. It was achieved through the reduction of requirements, relaxation of subsystem performance, and new approaches to selected operational crew safety and performance.

B. Minimum cost modules - In concert with Item A, the concept identified as Construction Shack was introduced as the major design theme for development in Part 3 and the preferred candidate for selection as the baseline system of the study. This was achieved through extensive application of Orbiter system hardware and the reduction of assigned volumes. A reduction in the initial SCM module complexity and associated cost was accomplished through utilizing Orbiter support to the maximum degree in the early Shuttle-tended missions.

C. Power Module and power platform - Replacement of the Part 2 Power Module with a combination of power sources resulted in both reduced initial and runout costs. The initial SCB power module is in the NASA preliminary planning phase as a auxiliary power source for extended Shuttle-Sortie missions at a power level of 25 kW at the bus. Following the Power Module is the power platform which is recommended for construction on-orbit at a power level of approximately 40 kW at the bus. However, the power platform has the addition advantage of being able to supply sufficient peak power to support the SPS Test Article 2 antenna power density tests.

In the latter phase of Part 3, following the development of a baseline program, emphasis was placed on the definition and comparison of several candidate SCB concepts. To address this task, the detail design data for both inboard and outboard concepts were developed in a building-block approach in order to permit rapid adjustment of configurations in response to operational changes and the final mission hardware design.

The underlying principle in the selection and definition of the SCB module and mission hardware elements was to assure system flexibility to support a wide variety of programs. This design approach provides the program planner with the fundamental equipment to establish specific programs in direct response to programmatic resources, objectives, and constraints. The mission elements depicted in Figure 5-14 are representative of their hardware classes.

The Orbiter, which represents the only near-term space launch system, also provides primary support during the Shuttle-tended operational mode.

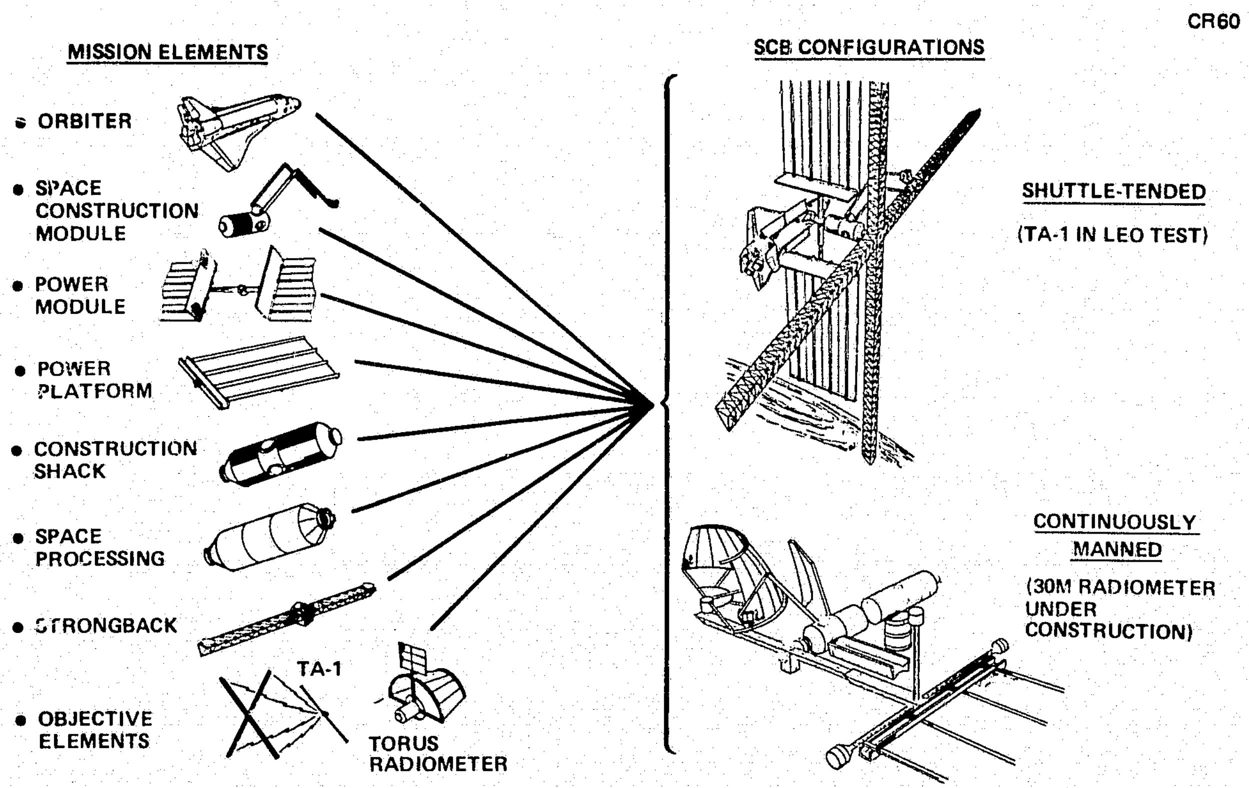


Figure 5-14. Typical SCB Concepts

The space processing facility category includes a variety of both development facilities and dedicated process optimization modules as well as scientific research facilities. A major class of mission hardware is represented by the strongback. It includes the space construction equipment which supports fabrication in both metals and composites. The SPS Test Article 1 and the 30 m torus radiometer are only two of several structures which could be fabricated. Additional elements encompass larger torus radiometers (up to 300 m), additional SPS Test Articles and multibeam lens antennas.

Two typical SCB configurations are shown to identify the two orbital operational modes which were evaluated in the study. These are: (1) Shuttle-tended, in which the Orbiter provides all crew support and a major share of the SCB's operational support and (2) continuously manned, in which the Orbiter supplies only the launch transportation and periodically is docked to the SCB for several days to transfer crew, cargo, and consumables.

The concepts at the subsystem, module, and station levels represent a practical and viable path to achieve adequate initial capability with economical growth to a larger, more flexible SCB.

5.4.2 SCB External Configuration Design Drivers

In the iterative process of determining desirable external configurations for the SCB, all key external system and subsystem requirements were delineated and evaluated as design drivers. For each of the design drivers selected and listed in Table 5-4, the operational requirements associated with the item were detailed, its physical characteristics noted, and design considerations outlined. A summary of this information is included in the subsequent portions of this subsection. In addition, selected design drivers which required detailed analytical definition have been included in Appendix 2. From this information, candidate external configurations were initiated and an iterative modification and selection process evolved following the guidelines and design considerations associated with the various design drivers.

Table 5-4

SCB EXTERNAL CONFIGURATION DEFINITION DESIGN DRIVERS

Report Section	Category	Design Drivers
5.4.2.1	Guidance and Control Subsystem	• Power platform solar orientation • Guidance/navigation sensor location • Drag makeup approach • RCS locations
5.4.2.2	Orbiter Interfaces	• Orbiter docking locations - normal and emergency • Orbiter flight corridor/envelope • Docking/berthing mechanism
5.4.2.3	Space Construction Base	• Module handling - buildup sequence • Space construction clearance envelope • Crane/RMS reach envelopes • Radiator locations • Communication antenna locations • Visibility considerations • EVA movement corridors - normal and rescue procedures • Test pointing requirements

5.4.2.1 Guidance, Navigation and Control Subsystem

Power Platform Solar Orientation – The power platform will require high average power output for certain mission profiles. These profiles include power platform testing, SPS TA-2 antenna testing and any other objective element requiring high average power output. The solution offering maximum power by orienting the solar cell plane perpendicular to the sun requires high RCS propellant consumption rates because of the severe gravity gradient torques. Therefore, this solution can be relegated to short-term (a few orbits) applicability. Long-term mission applications favor orientations in which the principal inertia axes are close to parallel/orthogonal to the gravity vector in order to null the gravity gradient (and small aero) torques.

Two orientations that satisfy the torque null conditions and maintain the power platform at a relatively high solar power level have been devised: one for low solar beta angles and one for high solar beta angles. The low beta angle orientation has the long axis of the power platform perpendicular to the orbit

plane and the normal vector to the power platform solar cells in an inertial orientation rolled toward the sun. The power factor for this orientation is cos β. The SCB modules point toward the earth to minimize gravity gradient torques and to present favorable geometry of the module radiator surfaces relative to the sun.

The high beta angle orientation has the long axis of the power platform vertical, with the solar cell normal vector rolled toward the sun. This orientation provides a variable power factor with a maximum of 1.0 at the ± 90 degree points from orbit noon, and a minimum of sin β at orbit noon (0 degree). The SCB modules will nominally point perpendicular to the orbit plane.

The power factors for both orientations (assuming zero principal axis tilt) are shown in Figure 5-15. It is indicated that the crossover for the choice of high-β vs low-β orientations is at $\beta = 33$ degrees with a minimum power factor of 84 percent. Thus, the combination of the two orientations can assure high power for all orbit conditions.

As is apparent from Figure 5-15, the high beta orientation provides good power factor even at low values of beta angle. Since other analyses in the study have shown that the high-beta orientation is also a low-propellant consumption condition for an all-RCS actuation system, it constitutes a leading candidate for the long-term orientation of the SCB. (Reference Appendix 3.)

Guidance/Navigation Sensor Location — The primary attitude reference for the SCB configuration uses stellar/initial sensors with transformations to orbit coordinates utilizing the ephemeric update navigation system. The stellar system with nongimballed star trackers with narrow field of view (± 5 degree cone) provides more physical flexibility than a horizon tracker system that gyrocompasses utilizing simpler software. The necessity for physical flexibility stems from the wide variety of configurations (limiting the field of view of optical sensors), orientations ("down" relative to SCB geometry can be in a wide variety of directions), and principal inertia axis

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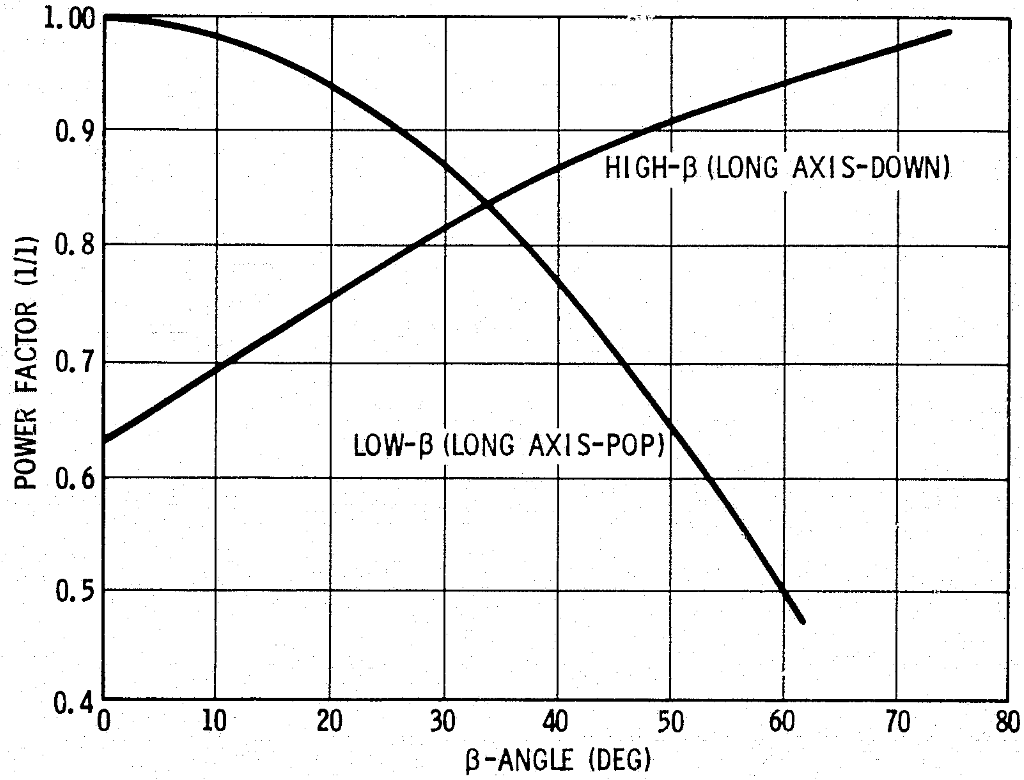


Figure 5-15. Power Factor For High Power Orientations

tilt (requiring skewed orientations). A horizon sensor system would require at least three sets of four horizon sensors, each set with a gimballed base. The realizability of such a system would be compromised by the field of view (FOV) requirements for the horizon sensors which are a narrow fan with a span of at least 90 degrees.

The installation of the stellar/inertial sensors in the Construction Shack is shown in Figure 5-16. Four star trackers are shown, each aimed at a different quadrant. Two operating trackers are considered to be the minimum required for high accuracy operation, and, since two may be obscured by the earth, a minimum of four will be required. They will be referenced together and to the IMU through a collimation system. A single, nongimballed set of horizon sensors is included to provide initial conditions for star acquisition.

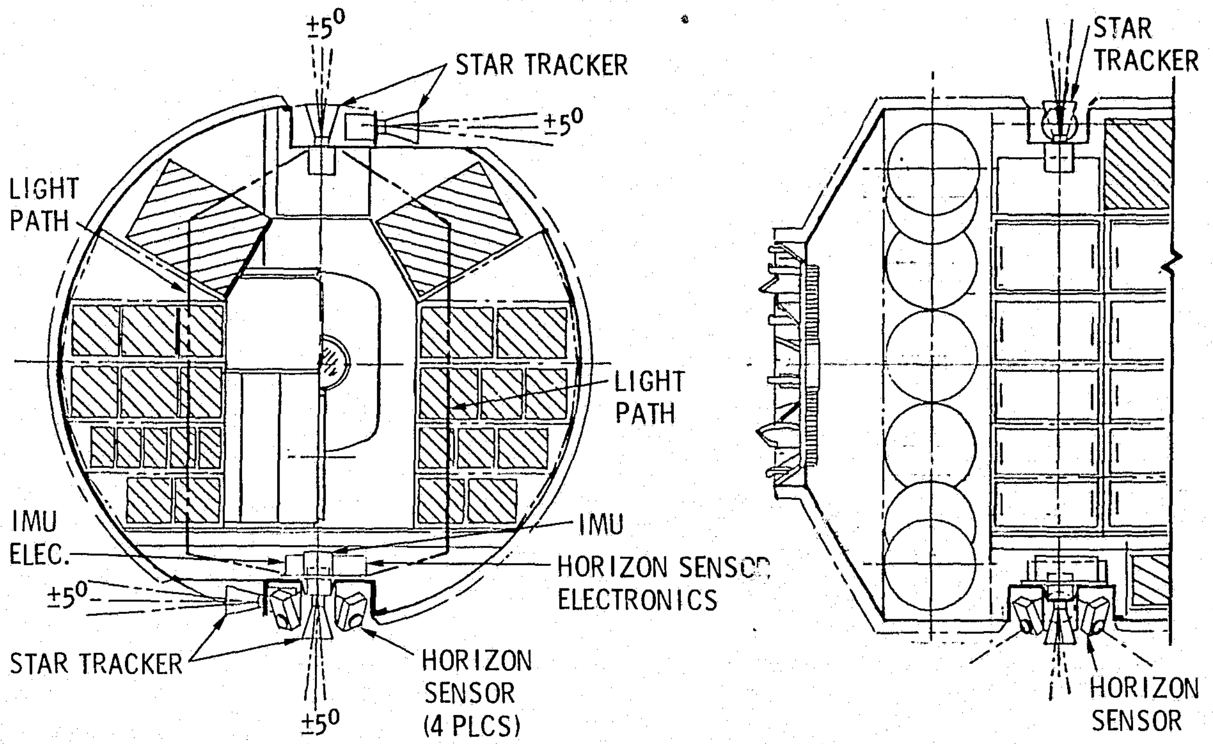
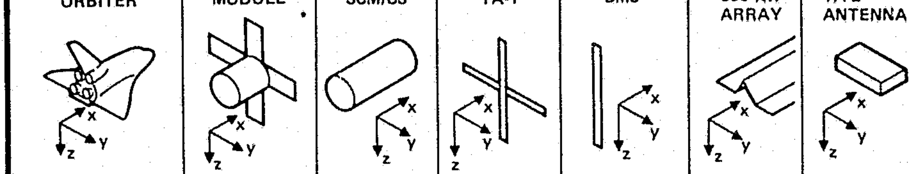


Figure 5-16. Installation of Stellar/Inertial Sensors

Drag Makeup Approach – The function of orbit-keeping is to maintain a consistent orbit compatible with operational requirements. Since allowing large decay excursions due to drag contributes additionally to orbit-keeping propellant requirements, frequent orbit-keeping will be desired. This allows the propellant impulse to be equal to the time integral of the drag. Since orbit decay rate is proportional to W/C_DA, high drag and low weight orbital configurations require more frequent orbit-keeping maneuvers. When orbit-keeping maneuvers are performed, the average of the orbit-keeping and control thrust should pass through the CG of the SCB.

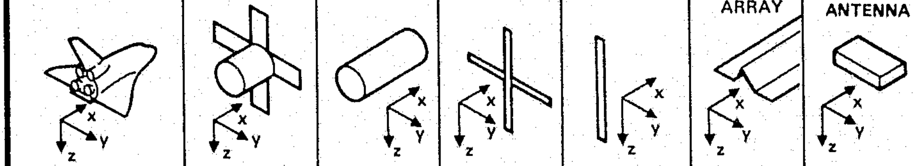
Figures 5-17 and -18 summarize the drag, acceleration, W/C_DA, lifetime, and orbit-keeping requirements for the various building blocks of an SCB. The conditions for Q_{MAX} and Q_{MIN} correspond to maximum solar activity and minimum solar activity. (Reference Appendix 3.)

RCS Locations – Figure 5-19 represents the CG of in-plane components for typical groupings of SCB configurations using the baseline RCP system for attitude control moments. One group represents the CG before the CS is

VEL ALONG			ORBITER	POWER MODULE	SCM/CS	TA-1	BMS	500 KW ARRAY	TA-2 ANTENNA
CONFIG-URATION									
	WT (LB)		~160,000	~4,000	~30,000	~6,500	~9,400	~10,000	~7,000
X AXIS	C_DA (FT^2)		1,380	17,600	624	3,970	3,940	12,200	290
Y AXIS	C_DA (FT^2)		5,050	1,800	1,670	3,490	3,940	44,500	290
Z AXIS	C_DA (FT^2)		8,390	1,800	1,670	3,490	3,940	134,500	725
X AXIS	W/C_DA (LB/FT^2)		116	0.23	48	5.7	2.4	0.82	24
Y AXIS	W/C_DA (LB/FT^2)		32	2.2	18	1.6	2.4	0.22	24
Z AXIS	W/C_DA (LB/FT^2)		19	2.2	18	1.9	2.4	0.07	9.7
X AXIS	LIFETIME FROM 450 KM (WK)		409	0.81	169	5.7	8.5	2.9	85
			2,500	5	1,040	35	52	18	518
Y AXIS	LIFETIME FROM 450 KM (WK)		113	7.8	64	6.7	8.5	0.78	85
			691	48	390	41	52	4.8	518
Z AXIS	LIFETIME FROM 450 KM (WK)		67	7.8	64	6.7	8.5	0.25	0.34
			410	48	390	41	52	1.5	210

Q_{MAX} (1991) = 1.79×10^{-6} PSF Q_{MIN} (1985) = 2.49×10^{-7} PSF

Figure 5-17. Lifetime, C_DA and W/C_DA Summary (Components)

VEL ALONG			ORBITER	POWER MODULE	SCM/CS	TA-1	BMS	500 KW ARRAY	TA-2 ANTENNA
CONFIG-URATION									
	WT (LB)		~160,000	~4,000	~30,000	~6,500	~9,400	~10,000	~7,000
X AXIS	DRAG ACCEL. (G'S)	Q_{MAX}	2.5×10^{-3}	3.2×10^{-2}	1.1×10^{-3}	7.1×10^{-3}	7.0×10^{-3}	2.2×10^{-2}	5.2×10^{-4}
		Q_{MIN}	3.5×10^{-4}	4.4×10^{-3}	1.6×10^{-4}	9.9×10^{-4}	9.8×10^{-4}	3.0×10^{-3}	7.2×10^{-5}
Y AXIS	DRAG ACCEL. (G'S)	Q_{MAX}	9.0×10^{-3}	3.2×10^{-3}	3.0×10^{-3}	6.2×10^{-3}	7.0×10^{-3}	8.0×10^{-2}	5.2×10^{-4}
		Q_{MIN}	1.3×10^{-3}	4.5×10^{-4}	4.2×10^{-4}	8.7×10^{-4}	9.8×10^{-4}	1.1×10^{-2}	7.2×10^{-5}
Z AXIS	DRAG ACCEL. (G'S)	Q_{MAX}	1.5×10^{-2}	3.2×10^{-3}	3.0×10^{-3}	6.2×10^{-3}	7.0×10^{-3}	2.4×10^{-1}	1.3×10^{-3}
		Q_{MIN}	2.1×10^{-3}	4.5×10^{-4}	4.2×10^{-4}	8.7×10^{-4}	9.8×10^{-4}	3.3×10^{-2}	1.8×10^{-4}
X AXIS	DRAG FORCE (LB)	Q_{MAX}	1.7×10^{-8}	7.9×10^{-6}	3.7×10^{-8}	1.1×10^{-6}	7.5×10^{-7}	2.2×10^{-6}	7.4×10^{-8}
		Q_{MIN}	2.3×10^{-9}	1.1×10^{-6}	5.2×10^{-9}	1.5×10^{-7}	10^{-7}	3.0×10^{-7}	10^{-8}
Y AXIS	DRAG FORCE (LB)	Q_{MAX}	6.0×10^{-8}	8.0×10^{-7}	10^{-7}	9.6×10^{-7}	7.5×10^{-7}	8.0×10^{-6}	7.4×10^{-8}
		Q_{MIN}	8.3×10^{-9}	1.1×10^{-7}	1.4×10^{-8}	1.3×10^{-7}	10^{-7}	1.1×10^{-6}	10^{-8}
Z AXIS	DRAG FORCE (LB)	Q_{MAX}	1.0×10^{-7}	8.0×10^{-7}	10^{-7}	9.6×10^{-7}	7.5×10^{-7}	2.4×10^{-6}	1.9×10^{-7}
		Q_{MIN}	1.4×10^{-8}	1.1×10^{-7}	1.4×10^{-8}	1.4×10^{-8}	10^{-7}	3.3×10^{-6}	2.6×10^{-8}
X AXIS	ORBIT KEEP PROP. (LB/MO) (270 I_{SP})	Q_{MAX}	24	302	11	68	68	209	5
		Q_{MIN}	3	42	2	10	9	29	1
Y AXIS	ORBIT KEEP PROP. (LB/MO) (270 I_{SP})	Q_{MAX}	86	31	29	60	68	764	5
		Q_{MIN}	12	4	4	8	9	106	1
Z AXIS	ORBIT KEEP PROP. (LB/MO) (270 I_{SP})	Q_{MAX}	145	31	29	60	68	2,304	13
		Q_{MIN}	20	4	4	8	9	321	2

NOMINAL ALTITUDE = 450 KM

Figure 5-18. Drag, Acceleration, and Orbit-Keeping Summary (Components)

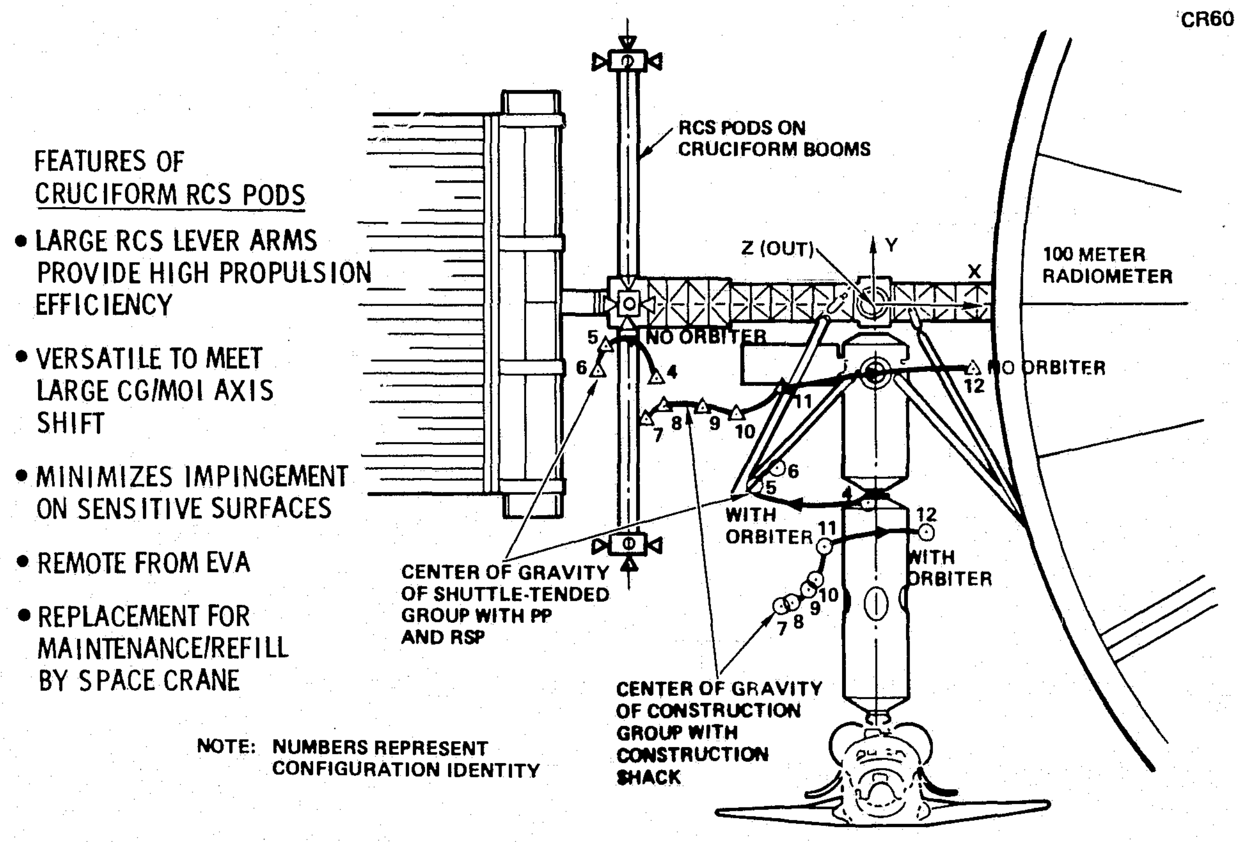


Figure 5-19. SCB Center-of-Gravity Shift

installed, and the other represents the CG with the CS installed. The arrows represent the movement of the CG for an assumed order of configuration buildups. They are, in fact, unconnected relative to time. Each point represents a completed configuration starting from the first data point in the group. The 100 m radiometer is shown as a typical objective element. The CG's are shown both with Orbiter and without Orbiter. The conditions with Orbiter have an additional out-of-plane component that varies from 6 to 12 m. The presence of the Orbiter also can result in a moment-of-inertia principal axis rotation as high as 33 degrees from the geometrical axes. These effects are primarily due to the displacement of the Orbiter CG from its docking axis.

As shown, the CG's with Orbiter are close to the SCM. If an RCS is included on the SCM, its small average lever arm, combined with cross-axis coupling, will result in at least three times the propellant expenditure that is required with the RCP. The RCP system provides minimum propellant also for the non-Orbiter cases in which the construction of heavier objective elements brings the CG close to (and even across) the SCM.

The remoteness of the RCP from the construction area (where most EVA will occur) and the SCM and CS will minimize impingement and contamination effects. Further, adequate redundancy in control is available with four pods in case of a thruster (or pod) failure or if it is necessary to restrict thruster firings through the software. The pods will be accessible to the space crane for replacement with new units for ground maintenance and/or refill.

5.4.2.2 Orbiter Interfaces

Orbiter Docking Locations – The primary location of the Orbiter for the delivery and berthing of various SCB modules is along the X axis of the Construction Shack/Space Construction Module Assembly, as shown in Figure 5-20. The primary location was selected to minimize consumables transfer distance from within the Orbiter to storage locations within the CS. Following completion of the docking sequence, the RMS and/or the SCB crane removes the payload from the Orbiter cargo bay and berths it into a designated port.

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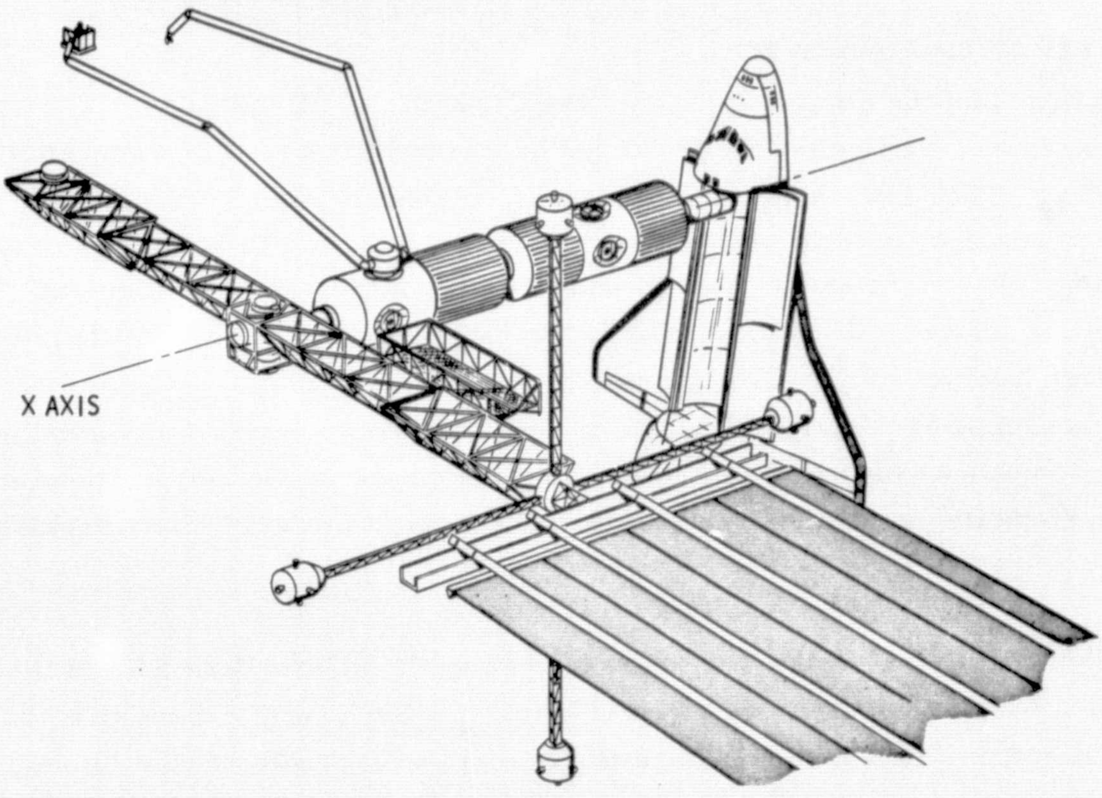

Figure 5-20. Primary Docking Location (X Axis)

Alternate docking locations are available; the principal one is on the X axis at the strongback core section, as shown in Figure 5-21, and on the Z axis as shown in Figure 5-22. The alternate locations provide added flexibility to the delivery of special modules or pallets dedicated to a specific construction site with minimum crane maneuvers.

In an emergency situation the Orbiter will dock to any operational-safe berthed module at any open axial or radial berthing port on the CS. Analysis of the available berthing port clearance envelopes and the Orbiter's flight approach corridor determined that there is access to each module for rescue operations.

Thus, each basic Orbiter location satisfies the Orbiter flight corridor requirements which are defined as "a corridor which extends 2m beyond the largest point of an envelope obtained by rotation of the orbiter about its C-G."

Orbiter Flight Corridor/Envelope — During space construction activities, Orbiter docking operations will necessarily be constrained to specific corridors to prevent inadvertent collisions. The corridors will extend from the rendezvous points to all module docking ports. Rendezvous will generally occur after a series of braking maneuvers until a standard offset radius point is reached. After rates have been nulled a transition maneuver that would minimize RCS plume impingement on the SCB would occur. It will bring the Orbiter along the velocity vector or along a line at right angles to the velocity vector for the final docking maneuvers.

Originally, a concern for translation-rotational coupling due to imperfect arrangement of the Orbiter thruster with respect to the center of mass, and particularly that occurring under a thruster out condition, resulted in a wide corridor being established. However, control response characteristics are such that only a 3 degree deviation in attitude should occur under these conditions before automatic corrective action occurs. As a result, an envelope of only 2m beyond the Orbiter extremities has been established as

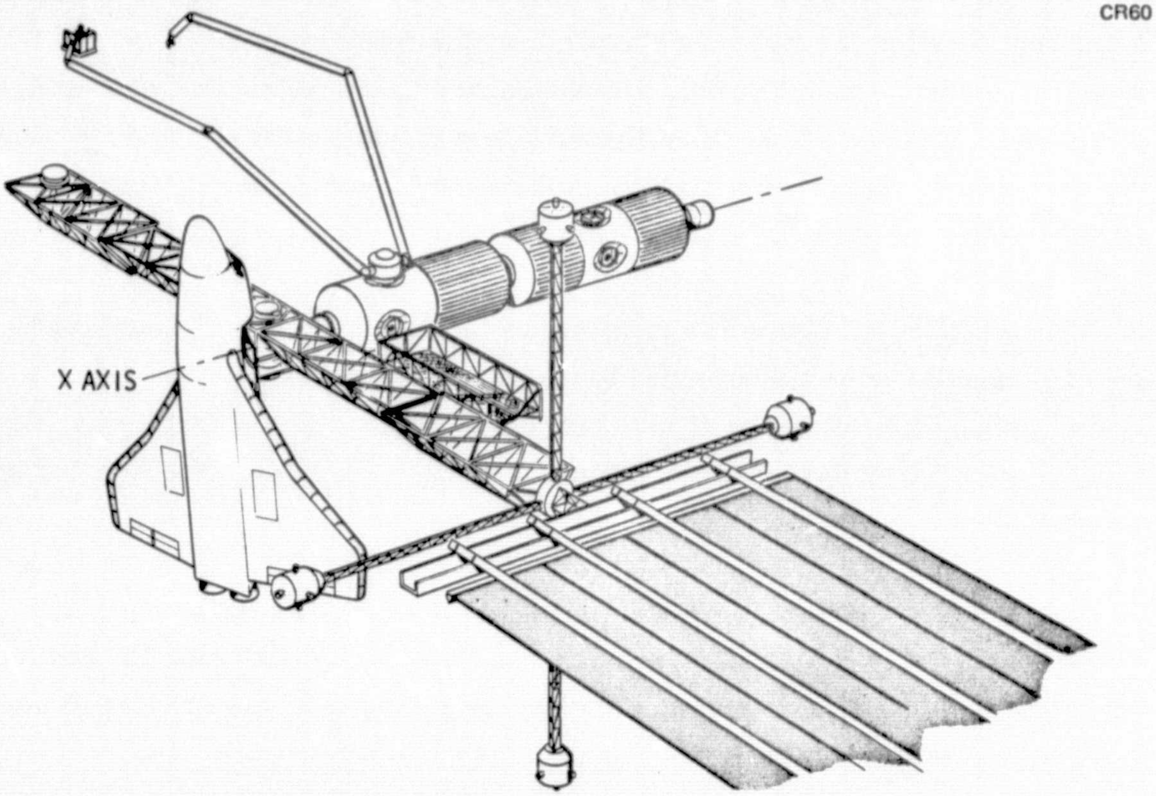

Figure 5-21. Alternate Docking Location (X Axis)

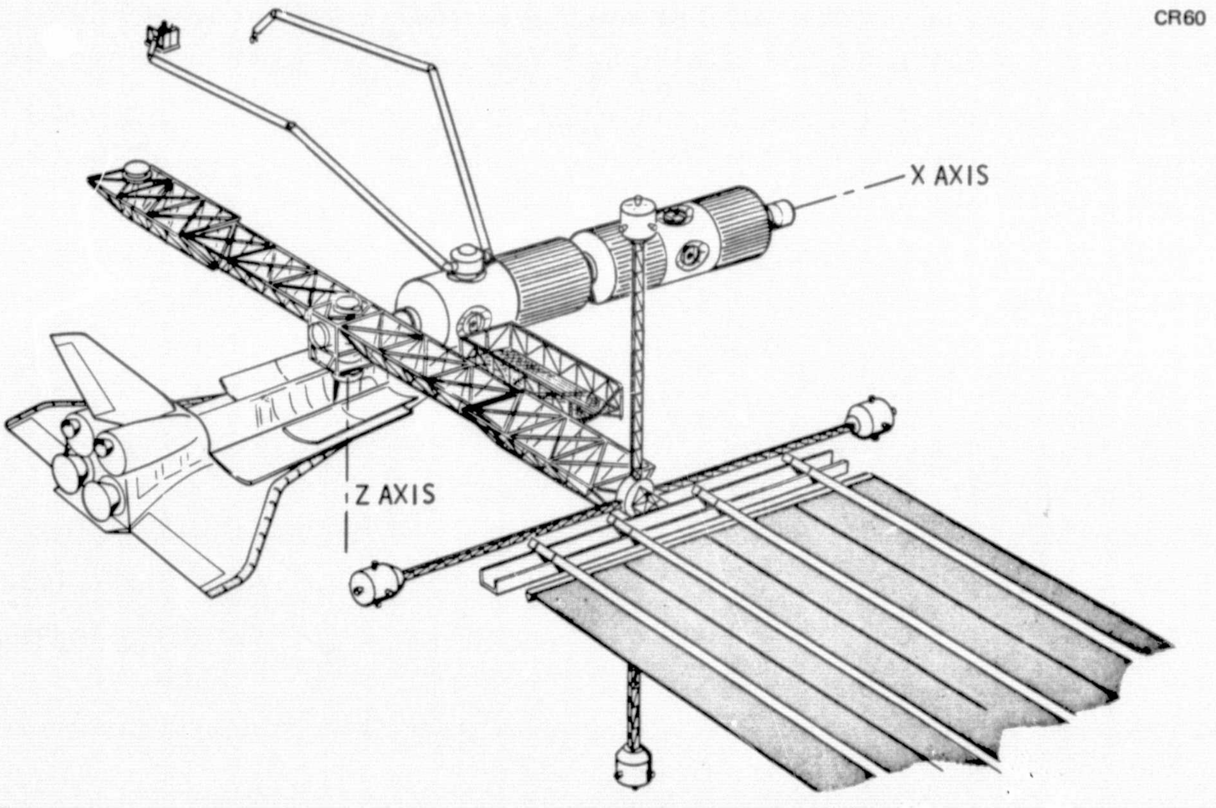

Figure 5-22. Alternate Docking Location (Z Axis)

a safe margin. The corridors are then defined by translation of the envelope along the docking vectors.

Docking/Berthing Mechanism – The Orbiter will be docked to the SCB by utilizing an Orbiter extendable docking module, as shown in Figure 5-23, with an active docking system. The module is installed in the Orbiter cargo bay, attached to the Xo = 576 bulkhead and support from the longeron and keel by payload attachment fittings. The docking ring plane extends from plane Zo = 457 to Zo = 515. Docking occurs at plane Zo = 515 which allows a 380 mm (15 in.) clearance above the mold line. The docking mechanism incorporated is an androgynous unit, shown in Figure 5-24, designed to function as either an active or passive mechanism for docking and undocking with an identical system. During docking operations, the Orbiter system is active and the mating SCB system is passive. The active system requires no assistance from the passive system. The Orbiter active system will perform the following functions:

A. Provide misalignment compensation to reduce the initial misalignment to values required to effect a successful capture.
B. Make the initial mechanical linkup (capture).
C. Absorb the impact energy and attenuate the loads to acceptable levels.
D. Limit vehicle rotational excursions.
E. Draw the structural rings together (retraction).
F. Mechanically connect and seal the structural rings.
G. Structurally adapt the docking module (DM) structural ring to the mating SCB and provide a nominal 80-cm-diameter, clear, pressurized passageway for crew and equipment intravehicular transfer.
H. Provide electrical bonding between the structural rings to prevent electrical potential difference between the docked spacecraft.
I. Release connecting mechanisms at any stage of the docking operation to effect undocking.
J. Provide a separation impulse for undocking.
K. Provide indications of system status and operation to the flight crew, including structural latch closed and individual latch loading indications.

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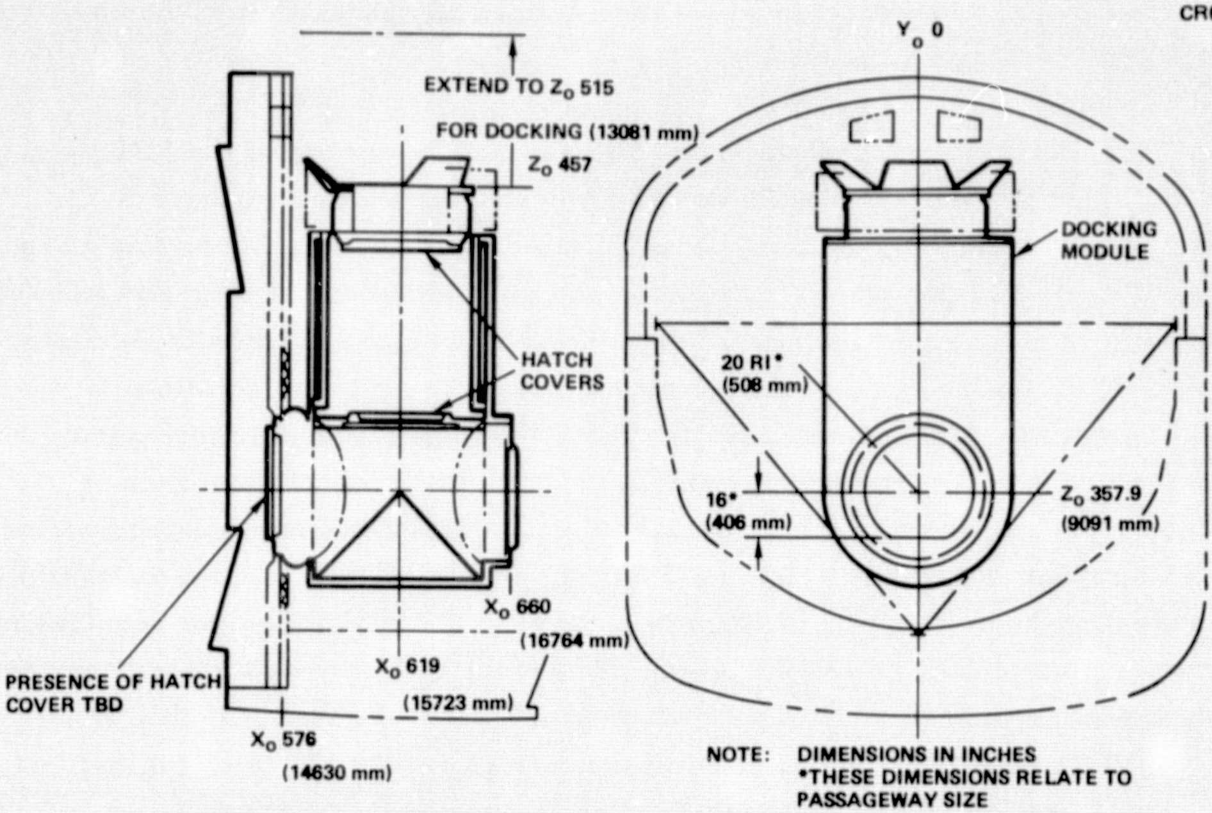

Figure 5-23. Docking Module

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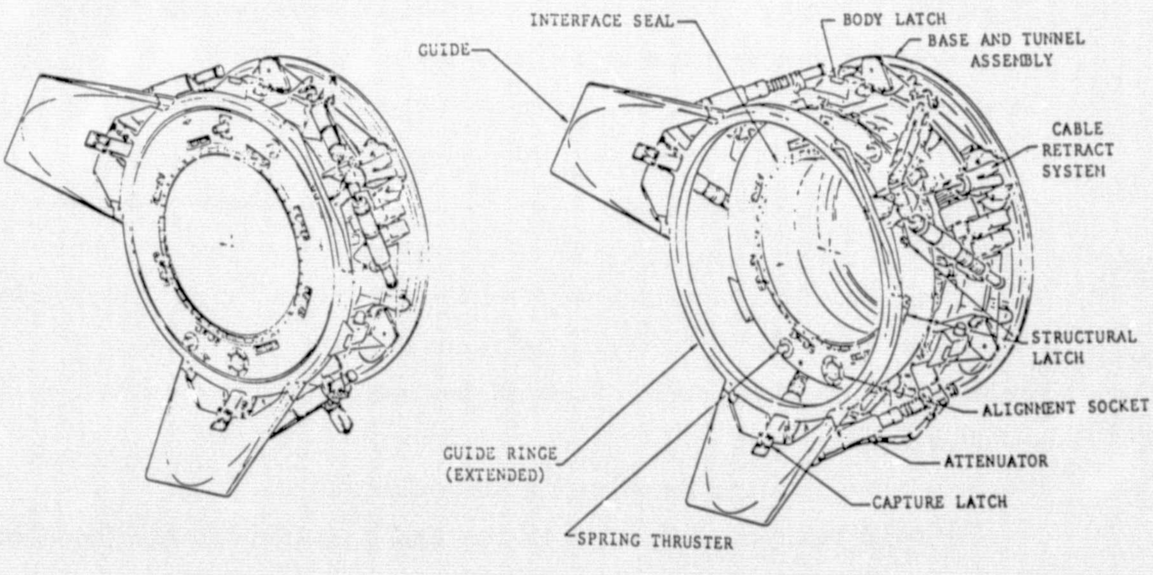

Figure 5-24. Orbiter Docking Mechanism, 40-Inch Diameter D-Shaped Hatch

L. Provide for emergency release of all connecting mechanisms to effect undocking.

The SCB passive system provides the structural and mechanical interfaces that are necessary to enable the active system to perform the docking and undocking operations. The passive system has the capability to effect an emergency separation from the active system.

Each system has three guides, located 120 degrees apart around the extendable guide ring. The guide ring of the active system is extended. The guide ring of the passive system is retracted. Impact energy is dissipated on the active system by six hydraulic attenuators.

The two docking systems are initially aligned to the correct orientation for capture and then structural latch mating by the interaction of the guides. Final alignment of the structural rings is performed by engagement of a pin and socket on each ring.

Two spring thrusters are mounted on each structural ring interface surface to provide initial separation velocity at undocking.

5.4.2.3 Space Construction Base

SCB Configuration Buildup — Definition of the SCB sequential buildup on an element-by-element basis was derived for the selected SCB system is consonance with related program plans and schedules. Each phase of the SCB buildup is summarized in Figure 5-25, which is a typical representation of a Shuttle-tended configuration, building up to a continuously manned construction base. During the initial phases of the buildup the Orbiter provides all life support function plus selected subsystem requirements that enable man to fabricate and assembly selected objective elements. During periods of time between Orbiter flights the SCB is placed in a quiescent mode. This sequence continues until the delivery of the Construction Shack which is configured to support a continuously manned operation. The initial step in the buildup consists of transportation of the Power Module to orbit and deployment of the solar arrays and heat rejection system. Then, the Space Construction Module (SCM) and crane are delivered and berthed to the power module by the RMS.

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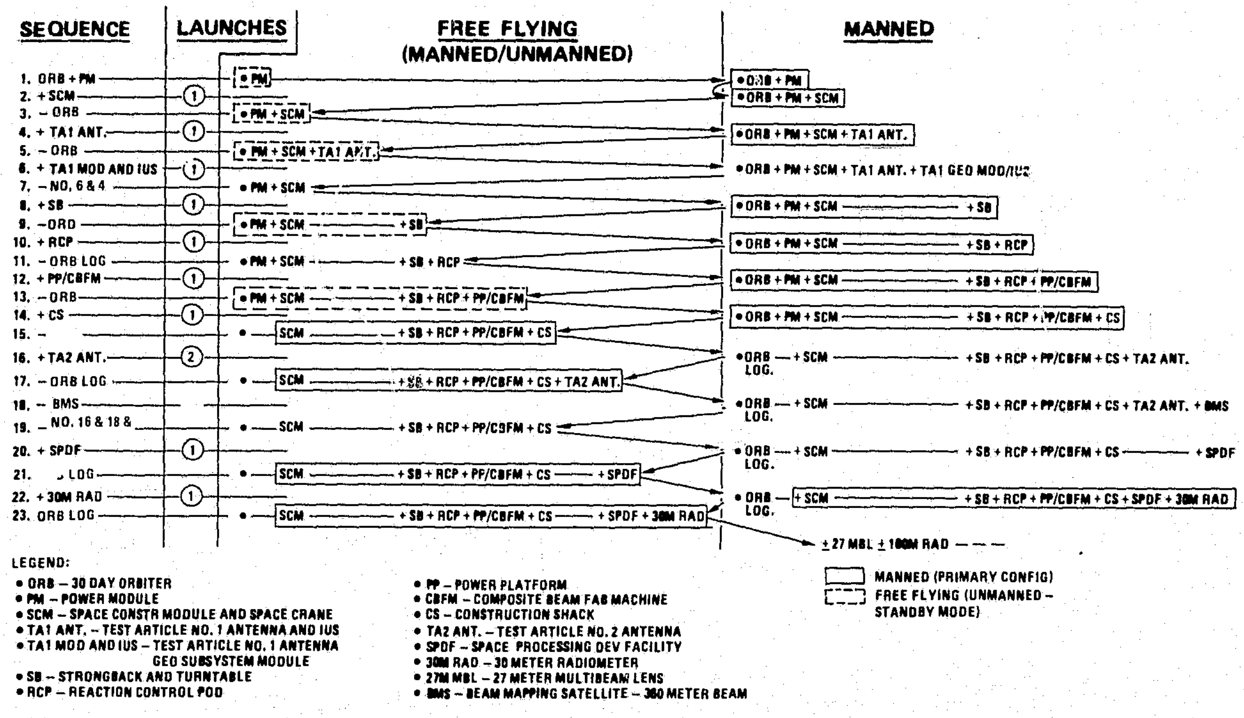

Figure 5-25. SCB Configuration Buildup/Accomplishment Sequence for Strongback Configuration

After the berthing of the Power Module and the SCB, the construction proceeds to the delivery and assembly of the TA-1 antenna system. After testing, preparations are made for GEO transfer by delivery and attachment of the satellite control system and the IUS's. The TA-1 antenna is then detached and transported to GEO orbit.

Subsequent to the construction and testing of the TA-1 antenna, the buildup and use of the power platform may proceed. Immediately following the completion of the PP, the Construction Shack (CS) is launched into orbit and the power module is removed. Following berthing of the Construction Shack, the SCB is then a continuously manned configuration. Then, delivery and deployment of the TA-2 antenna is accomplished, followed by its testing involving the Beam Mapping Satellite.

A Space Processing Development Facility (SPDF) may then be brought up and berthed to the CS. Next, the 30M parabolic torus radiometer components are delivered and berthed to the SCM and construction is undertaken. As defined

by the program plan, the 30M radiometer is followed by the 27M MBL and 100M radiometer, each delivered and assembled in the manner defined for the 30M radiometer.

Further details of the buildup sequences for the Shuttle-tended configurations and the continuously manned configurations, together with illustrations of each major step in the buildup sequence will be discussed in the latter portion of this Section.

Space Construction Clearance Envelope - The external geometry of the SCB-strongback configuration shown in Figure 5-26 resulted from a selection process which included evaluation of the relative positions, sequence, and size of various objective elements as they were to be constructed. The location of the objective elements such as the 27M Multibeam Lens, 30M Radiometer, and 100M Radiometer have a definite influence on size and location of the crane, material pallets, RCS pods, SCB modules, and the strongback. A basic clearance envelope of 3.5m was established as the minimum spacing of each objective element from the SCB. This clearance permits the berthing of a material pallet to the strongback with a 0.76m (30 in.) separation.

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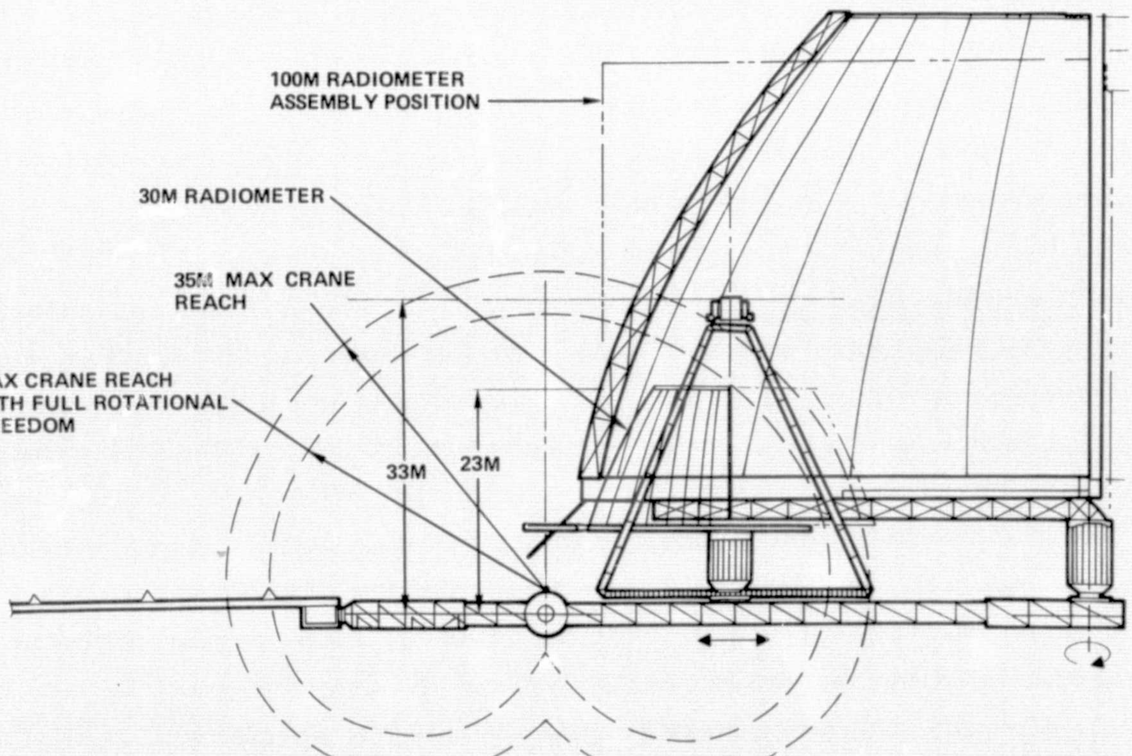

Figure 5-26. Space Crane Working Envelope

Assembly of the 30M Radiometer requires a construction clearance envelope as shown in Figure 5-26. Using the turntable to rotate the work past the work-station results in an envelope of approximately 30m dia x 23m high and locates the turntable up to 19m from SCB centerline. This clearance envelope is compatible with the crane working envelope, and does not limit the use of any radial berthing port. The assembly locations of the 27M Multibeam Lens (MBL), as shown in Figure 5-26, require a clearance envelope of approximately 29m in dia x 33m in height and requires the turntable to be located up to 17m from the SCB centerline. The MBL construction envelope is compatible with the crane working envelope; however, use of the radial berthing port of the SCM, adjacent to the construction site, is restricted during final assembly and checkout. Locating the construction site to remove the restriction results in placing the assembly beyond the crane reach capability.

The assembly location and procedure for the 100M Radiometer results in a maximum construction clearnace envelope of 104m dia x 65. 5m high, and places the turntable at a distance of 55. 5m from the SCB centerline. Assembly procedures, defined in Section 4. 4, utilize supplementary equipment to rotate the radiometer in two different orientations and to translate along the strong-back in order to keep all work stations within easy reach of the crane. This procedure results in a constantly changing construction clearance envelope, depending on stage of assembly. Time phasing of concurrent SCB operations, such as Orbiter docking and module berthing, will be required to permit rotating the assembly to prevent interference.

Crane Reach/Berthing Envelope - The solution chosen as being cost effective was to utilize the crane with 35m long arms and move the construction work to the crane as necessary. This concept is illustrated in Figure 5-26 which shows the reach envelope of a 35m crane positioned on the SCM of the SCB strongback configuration. The envelope of fully rotational end effector capability is about 4m less than the maximum reach due to the distance between the wrist and the tip of the end effector. Using the strongback fixture to move the work in and out, and an indexing turntable to provide rotation, each program element can be assembled within the crane reach envelope and deployed along the strong-back as desired. For very large program elements, special tooling will provide

a tilt capability to permit assembly within the working envelope of the crane. In order to reduce the probability of collision, facilitate direct operator visibility, and provide freedom of crane arm movement, no permanent fixtures will be placed in the upper hemisphere of crane operations.

The analysis of large structure construction techniques in the zero-g environment determined that it is necessary to: a) develop a crane with 25m to 35m arms, b) move the crane to the construction work, or c) move the construction work to the crane.

Radiator Locations - Potential radiator locations for integral radiators include the cylinder and cone ends of the SCM, CS and SPDF. Deployable radiator location options include any of the above modules, the strongback, Power Module, or power platform. Some of the key criteria for radiator location include:

- Development and fabrication cost
- Performance
- Integration and operational complexity
- Proximity to cooling loads
- Vulnerability to contamination or damage
- Weight, power and volume penalties.

Based on these criteria, integral radiators were located on the cylindrical portions of the SCM, CS, and Space Processing Development Facility (SPDF). These radiators are capable of rejecting the estimated heat rejection requirements of these modules. The integral radiator approach meets the above criteria; however, the use of deployable radiators is an option. Integration cost and complexity of integral radiators might be reduced by eliminating major structural interfaces between radiator and module by use of deployable radiators.

Deployed radiators for the Power Module were located on the shade side of the solar array supporting beam. This is a desirable location considering performance, structural support, and stowage during launch.

Communication Antenna Locations - Transfer of RF data will be at the S- and K-band frequencies as presently employed by the Orbiter. S-band omni-antennas are employed which may be placed in any convenient location on the modules having a field of view which is relatively unobstructed. Since these antennas are small, installations may be made with minimum difficulty. The primary criterion is that line lengths to the transmitters/receivers or power amplifiers be kept short to prevent excessive losses.

The Ku-band communications antenna, which is used for single or composite high-rate communications with the ground via TDRS, requires a different installation. On the Orbiter it is located at the stations shown in Figure 5-27 in the stowed and operating position. It provides a gain of 39.6 dB after deployment by a rotation of 143 degrees about the Z axis. A second antenna system can be provided (chargeable to the payload) to increase the coverage potential or period the satellites are in view.

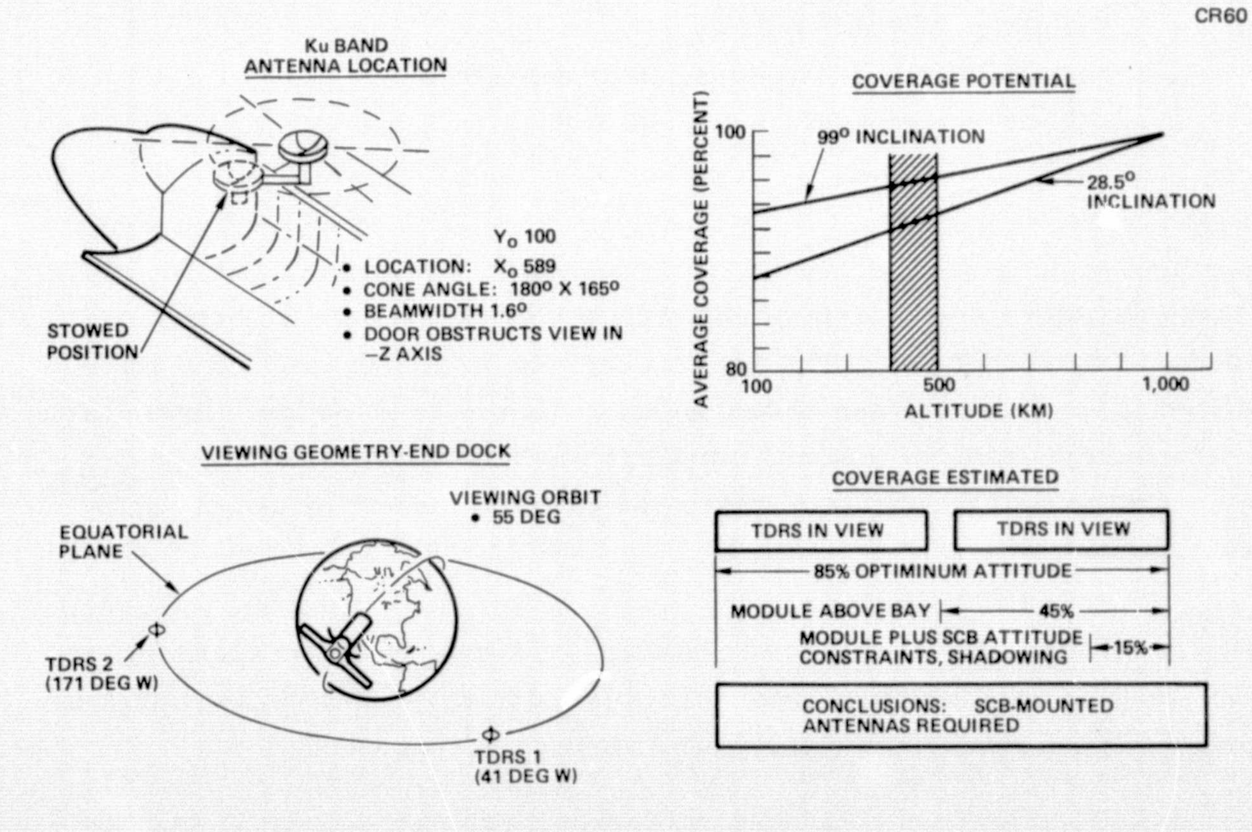

Figure 5-27. Orbiter Communication Antenna Location – View Angle

The coverage potential is illustrated as a function of altitude and inclination. This assumes that the attitude of the Orbiter may be constrained in order to provide the antennas a clear field of view except when the satellites are occulted by the earth. Since the Shuttle-tended SCB attitude is constrained by other factors, such as sun angle in relation to solar panels and the requirement to point antennas along the velocity vector, this coverage will be much reduced. In addition, the viewing geometry of the antennas will also be affected by the location of modules and construction above the docking port.

As a result of the combination of these adverse effects, it is estimated that with one antenna, a satellite will be in view only approximately 45 percent of the time with a SCB module above the bay. With attitude and shadowing constraints, this could possibly be reduced to 15 percent. Therefore, it appears necessary to provide the SCB with a set of boom-mounted antennas whenever high data rates must be supported. A mounting position on the strongback has been selected as providing the best look angles.

EVA Movement Corridors – Normal Movement and Rescue Procedures - In the Strongback SCB configuration, consisting of the Construction Shack Module, the Space Construction Module and the strongback, EVA movement corridors during normal operations consist primarily of egress and ingress at the Orbiter or Construction Shack airlocks, movement from the exterior of the Construction Shack Module to a cherry picker attached to a crane arm, or movement to the strongback truss and the construction area. During an Orbiter-tended mode of operation, in which the SCB consists of the Orbiter, the Space Construction Module, and a strongback truss, the EVA construction crewmen will don their suits within the Orbiter and egress through the Orbiter cargo bay. Translation close to the Orbiter and SCB modules will be by handrails or handholds.

Potential hazards within the Orbiter or the SCB lead to the probability of various safety procedures. These conditions and the safety and rescue modes of operation which can have a significant impact on the external configuration of the SCB were examined. The types of hazard sources considered are shown in Table 5-5. Although the resulting damage or failure mode may not be catastrophic, it will result in vacating the locale of the hazard to other regions of the SCB.

Table 5-5

TYPES OF HAZARD SOURCES

Type of Hazard	Damage or Failure Mode
• High pressure vessels	- Rupture
• Propellants	- Rupture, fire, explosion
• Toxic gases	- Atmosphere unusable
• Volatile fluids	- Toxic
• High voltage subsystems	- Arcing/shock, fire
• Materials	- Heat, smoke, fire
• Radiation	- Heat, radiation
• Orbiter docking mechanism jamming	- Reduced module access
• SCB berthing mechanism jamming	- Reduced module access
• EVA airlock	- Hatch failure (closed/open)

Candidate rescue procedures for the Shuttle-tended and continuously-manned operational modes are summarized in Table 5-6. These procedures are compatible with the strongback SCB configuration and may vary slightly during the early phases of buildup.

Test Requirements - Objective Elements - Testing of the objective elements following their construction imposes a number of requirements on the SCB. Test equipment must be provided to conduct: a) component tests of commonly used items in the event of failure or breakage, b) subsystem and all systems test prior to objective element release or transfer to synchronous orbit, and c) tests to determine that performance of the completed objective element is within tolerance. Within this last category are the tests to determine that antenna contours are within RMS error margins and that antenna patterns in the far field have the requisite beam widths and side lobe to main beam power ratios.

In order to assure surface contour tolerances, a laser alignment system consisting of laser beam transmitter, reflectors and receiver must be provided. Measurement of alignment using this equipment will be followed by a contour adjustment operation using panel skimming and/or cable tensioning.

Table 5-6

OPERATIONAL MODE AND CONDITIONS FOR RESCUE CASES

Operational Mode/Conditions		Rescue Procedure
Shuttle-Tended		
• Orbiter damaged		Shirtsleeve egress to CSM, Orbiter exchange
• Construction support module damaged		Shirtsleeve egress to Orbiter
Continuously-Manned SCB		
Orbiter Docked	Orbiter Not Docked	
• Orbiter damage		Shirtsleeve egress to CS, EVA to CS airlock
• Construction shack damage		Shirtsleeve egress to Orbiter or CSM, EVA to Orbiter or CS
	• Construction shack damage	Shirtsleeve egress to CSM, EVA to CS airlock
• Construction support module damage		Shirtsleeve egress to CS, EVA to Orbiter cargo bay airlock or CS airlock
	• Construction support module	Shirtsleeve egress to CS, EVA to CS airlock

Far-field tests for pattern contour mapping will employ beam mapping satellites which will also simulate RF emissions at various radiometry wavelengths and simulate ground transmit and receive operations over geosynchronous ranges. Figure 5-28 illustrates the use of a satellite in performing an MPTS test article beam mapping procedure. This particular satellite will be a standard NASA design with payload replaceable according to mission requirements. A second satellite with three pilot beam transmitters and numerous receivers is used to more closely simulate SPS operation.

To meet orbital test requirements, all antennas must be pointed along the velocity vector during testing, have a clear usually hemispherical field of view to prevent pattern distortion by multipath, and be capable of rotation ±10 degree off axis.

5.4.2.4 System Engineering Evaluation

An integrated evaluation of the preceding design driver information from both an absolute operational requirements and a relative interface effects standpoint was accomplished on a nonconfiguration-oriented basis prior to

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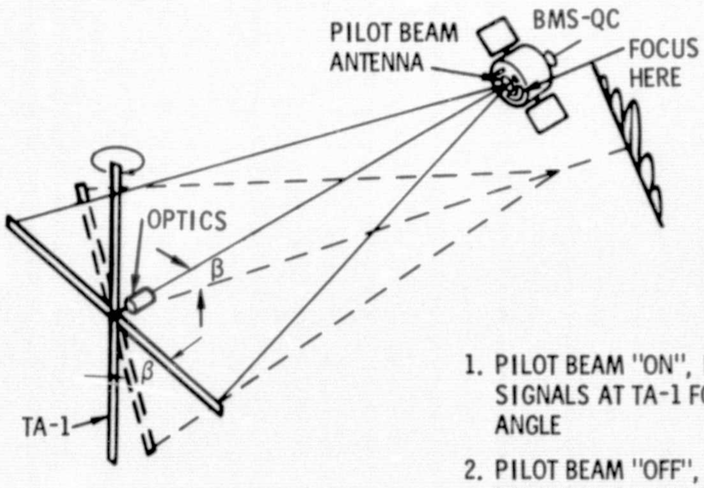

TEST ITEM	RANGE (Km)	β(DEG)
1. TA-1 BEAM MAPPING	258	±5
2. TA-2 BEAM MAPPING	3.4	±10
3. TA-1 & TA-2 RFI	1-258	±180

1. PILOT BEAM "ON", RECORD PILOT BEAM SIGNALS AT TA-1 FOR FIXED STEERING ANGLE
2. PILOT BEAM "OFF", PLAY BACK RECORDED SIGNALS TO MAINTAIN FIXED STEERING ANGLE
3. ROTATE TA-1 THROUGH ANGLE β* & RECORD FIELD STRENGTH IN BMS-QC
4. REPEAT FOR VARIOUS STEERING ANGLES

β* ARRAY NORMAL TO BMS LINE OF SIGHT ANGLE

Figure 5-28. Beam Mapping Test Procedure

addressing the merits and compromises of specific configurations. In general, there were no irreconcilable conditions; however, certain approaches were selected to minimize interference conditions and improve subsystem performance.

The first category of guidance and control introduced the most significant influences on the configuration due to the relatively dominant mass properties and drag effects of the power platform and large structural objective elements. However, as noted in the summary and appendix data, this can be compensated for by boom mounting of the reaction control pods and carefully programmed SCB orbital orientations.

Orbiter operations and interfaces do not impose conditions which contribute to either major safety problems or unusual configurations. The Orbiter's automated attitude control which holds the yaw/pitch disturbances to approximately ± 1 degree results in an approach corridor 2 meters larger than the maximum dimensions. This corridor permits the desired end-axis docking for normal logistics and at least one radial emergency port. In conjunction with this, the use of a docking/berthing transition tunnel permits full flexibility in the selection of the berthing mechanism and the utilization of berthing ports for Orbiter docking.

Finally, the SCB operational and clearance envelope requirements impose certain module/mission hardware relationships which can be accommodated in consonance with efficient buildup and operational procedures. The two most demanding design drivers which were used for establishing an initial framework of the SCB configuration are the construction clearance envelope (i.e., resulting from the 100-meter radiometer) and the antenna test requirement of a completely clear hemisphere in the transmission zone.

All of these design drivers were successfully incorporated in the definition of the SCB configurations presented in Subsections 5.4.3 and 5.4.4.

5.4.3 Shuttle-Tended SCB

The two primary system approaches for achieving the initial space construction capability are Shuttle-tended and continuously manned operational modes. Shuttle-tended is of particular interest due to the benefits which

accrue to the initial SCB program in the form of reduced initial subsystem complexity, number of modules, and associated lower costs. An additional beneficial consideration is the utilization of the Power Module currently being planned by NASA for support of the Shuttle-Sortie missions. Thus, with these mission elements available, the addition of a Space Construction Module completes the basic Shuttle-tended SCB.

5.4.3.1 Selected Configuration

The definition of the Shuttle-tended SCB which would meet program approach required that two orbital flight conditions be met: (1) the Power Module and Space Construction Module remain unmanned in orbital free-flight between Orbiter visits, and (2) manned operational flight while the Orbiter is docked. The SCB configuration which fulfills these conditions is shown in Figure 5-29 and the significant characteristics in Table 5-7. In the unmanned flight mode, all attitude control subsystem status reporting, thermal control, and docking stabilization are supplied by the Power Module, thus minimizing the complexity of the Space Construction Module.

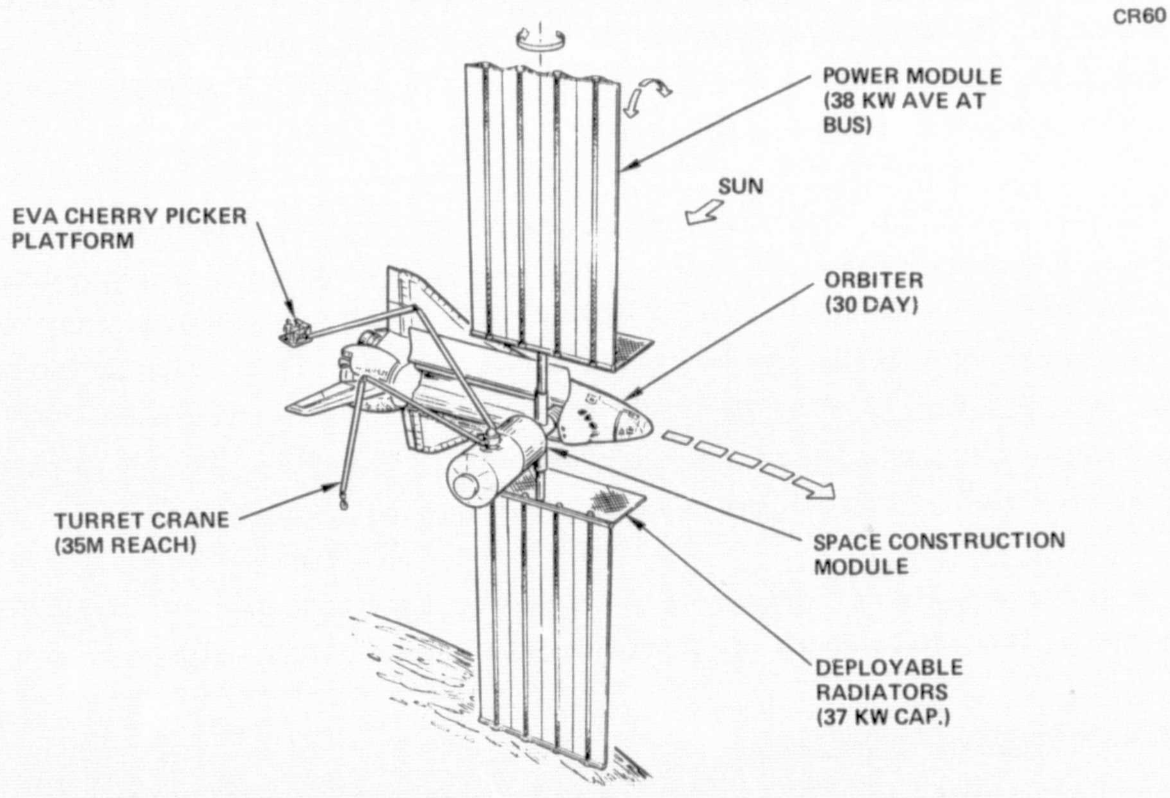

Figure 5-29. Shuttle-Tended SCB Concept

Table 5-7

SPACE CONSTRUCTION BASE CHARACTERISTICS (SHUTTLE-TENDED)

• Crew	- 4 to 7
• Shifts	- 1 or 2
• Modules	- Space Construction Module, Power Module
• Mission Equipment	- Strongback, Crane
• Mass	- 28,409 kg (62,500 lbs)
• Pressurized Volume	- 109 m^3 (3850 ft^3)
• Power (Bol) at Array	- 89 kW
• Array Area - 2 wings	- 1000 m^2 (10,758 ft^2)
• Power (Bol) at Bus	- 38 kW
• Heat Rejection	- 37 kW
• Radiator Area	- 141 m^2 (1517 ft^2)
• RCS Propellant	- Orbiter, RCS, PM-CMGs

In the manned mode, the crew support, consumables supplies, and habitability are provided by the 30-day Orbiter. In addition, the SCB operational support subsystems are located in the Orbiter or Power Module. The Orbiter provides data management, communications, attitude control, and beam mapping satellite control, while the Power Module provides power reaction control and thermal-control/heat-rejection. Construction support is concentrated in the module (e.g., supervision, planning, crane control), with the utilization of available Orbiter resources, as appropriate, for the EVA activities. This is primarily in the use of the Orbiter's EVA airlock, which is sized to accommodate two-suited crewmen. Although this is adequate for multiple EVA shift support, it has been augmented by the addition of an EVA support area in the Space Construction Module which will support all EMU maintenance and daily refurbishment.

Maximum growth flexibility is one attribute of this initial configuration. A strongback can be constructed as a next step, the power platform construction is a second alternative, or the TA-1 antenna system can be assembled and then oriented for testing.

The configuration is optimally oriented with regard to the sun-solar array aspects as well as minimum drag considerations. The orientation is adequate for both low and high beta angle situations.

The configuration has excellent capability to support a range of objective elements for any construction mode, i.e., deployment, assembly, or fabrication. This includes the SPS Test Article No. 1, SPS Test Article No. 2 Antenna, 27M Multibeam Lens Satellite, and the 30M Torus Radiometer Satellite.

For example, the SPS Test Article No. 1 assembly is accomplished in a Shuttle-tended mode using the 35m crane on the Space Construction Module (Figure 5-30). A telescoping standoff assembly fixture is located at one end of the SCM and, after completion of structural and electrical component installation in LEO, the antenna is oriented for testing, as shown. After testing, the telescoping fixture is extended and preparations are made for GEO transfer. Installation of satellite control systems is made for GEO operation and interim upper stage (IUS) attachment made for launch to GEO. The TA-1 antenna is then detached and transported to GEO orbit.

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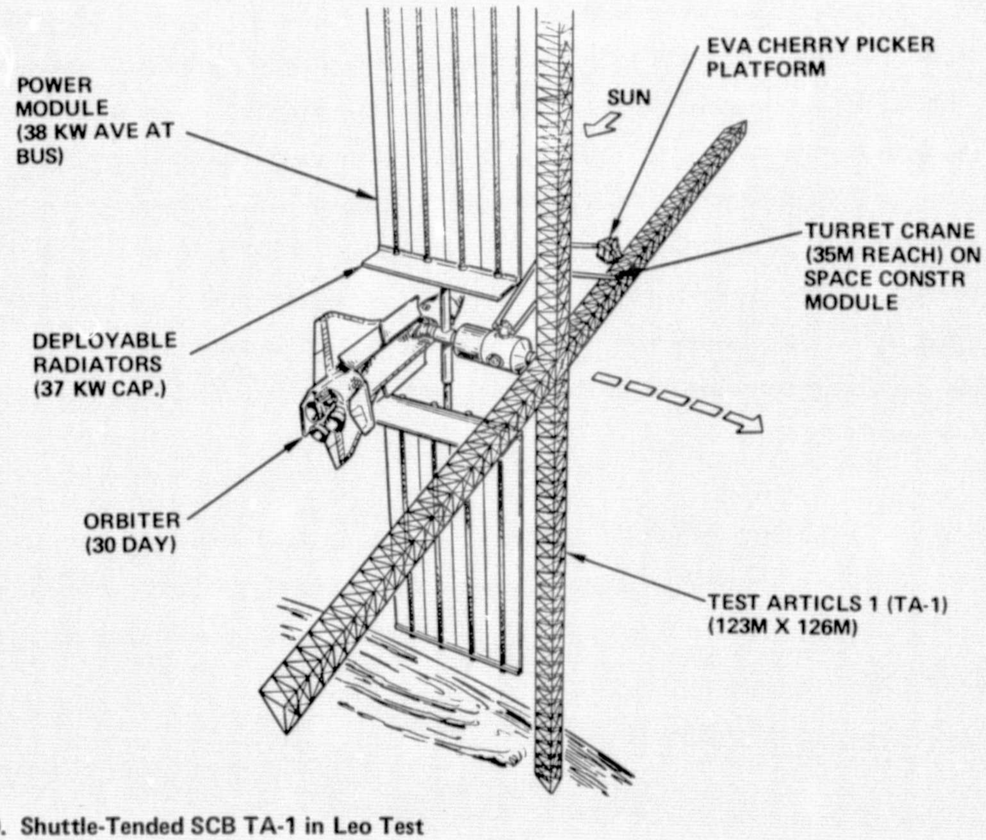

Figure 5-30. Shuttle-Tended SCB TA-1 in Leo Test

Although construction of the 300m radiometer satellite would tax this mode, the space fabrication of the 250 kW peak power platform can be accomplished as shown in Figure 5-31.

Also shown are the four RCS pods attached to support beams at the end of the strongback. These pods contain approximately 1800 kg (4000 lbs) of N_2O_4/MMH each, which is sufficient for 120 days of operation, and are required for the increased mass properties associated with the power platform and large objective elements. As this subsystem is critical to SCB safety through control of orbital drag for orbit keeping, the pods are replaceable and have been configured for ground servicing and maintenance. Although a propulsion system is required for orbit keeping, analysis of control moment gyros (CMG's) for attitude control determined that utilization of three Skylab class CMG's was also feasible under closely controlled limit-cycle conditions.

Construction of the power platform using the composite beam integral web technique will require about 30 days, with the solar blanket installation being

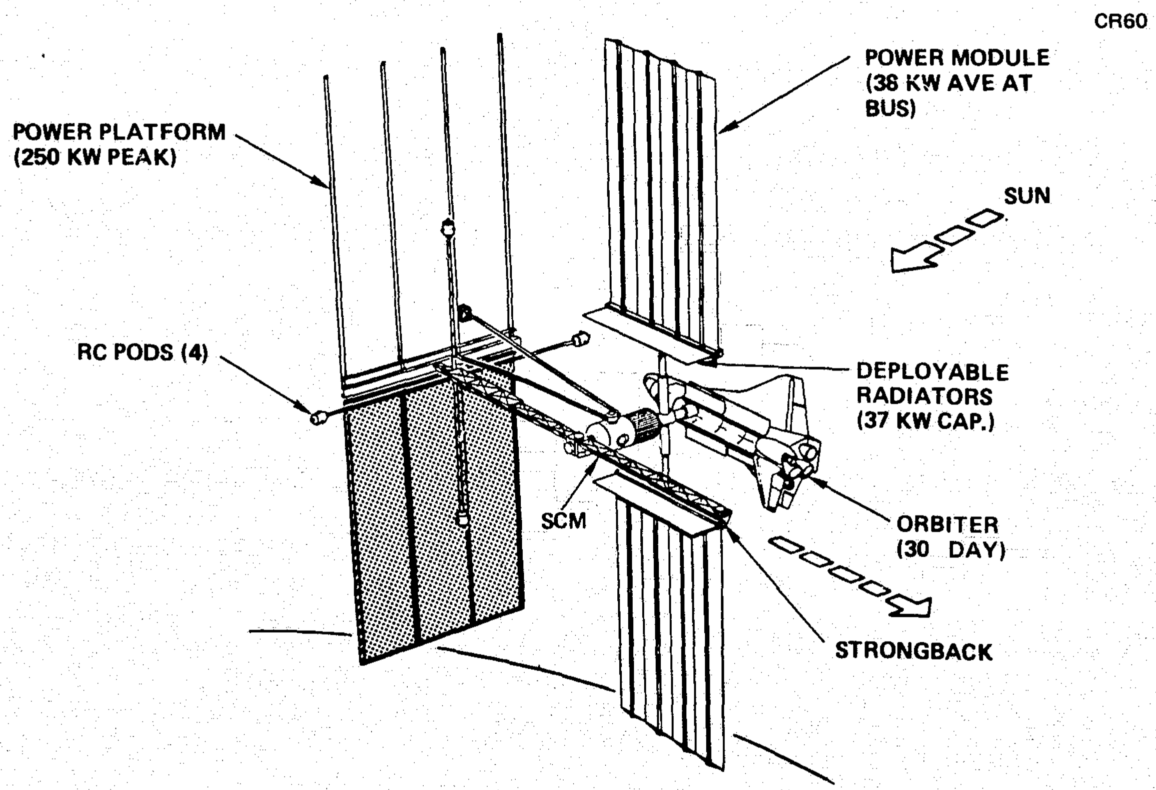

Figure 5-31. Shuttle-Tended SCB Power Platform Under Construction

completed in 3 to 4 days. Thus, the drag factor associated with the power platform will not have significant impact on propellant requirements and the plane of the platform will be in a favorable orientation with respect to the sun during construction. Completion of the power platform will ready the SCB for TA-2 antenna construction and subsequent assembly of the 30M Radiometer.

5.4.3.2 Orbital Buildup Sequence

The initial module delivered to orbit is the Power Module (PM). After the solar arrays and radiator systems are deployed and operational integrity of the module has been verified by the Orbiter crew, the Power Module is released. The module is left in a nominally quiescent state until scheduled launch of the Space Construction Module. After the PM has been docked to the Orbiter, the SCM is deployed from the cargo bay by means of the PIDA. During verification of subsystems, the RMS removes the space crane components from their launch position and assembles them in the operational configuration. The RMS then berths the SCM to the X-axis of the PM as shown in Figure 5-29. The SCB is now configured to initiate routine construction activity associated with the program plan sequence. The resultant orbital configuration of the Shuttle-tended SCB shown in the figure, consists of the Orbiter, Power Module, and SCM. The SCM incorporates four radial berthing ports and two axial ports for attaching assembly jigs, material canisters or pallets to the side of the module. Thus, the crane can transport material directly from the pallet directly to the assembly fixture, or can supply raw material directly to fabrication machines. According to the program plan sequence, the construction proceeds to the assembly of the TA-1 antenna system. The 123-m long x 126-m long crossed arm antenna is delivered in a collapsed configuration stored on a pallet. Using the SCB crane, the pallet is removed from the Orbiter cargo bay and berthed to one of the radial berthing ports on the SCM. The pallet is unfolded and each antenna segment is deployed, electronics installed, and joined to other segments until the arms of the antenna are complete. As each arm is complete, it is installed on the holding fixture and oriented for testing. After testing, the Orbiter returns with the TA-1 satellite control systems and the IUS's for GEO operation. After the installations are made, the TA-1 antenna is detached from the SCB and transported to GEO. Subsequent to the construction and testing of the TA-1 antenna, the buildup of the SCB to fabricate

and assemble remaining objective elements may proceed. Following docking of the Orbiter to the PM/SCB facility, the crane removes the folded truss beam strongback from the Orbiter cargo bay and berths the assembly core structure to the SCM. Each of the triangular truss beams is rotated and locked into place and the Reaction Control System (RCS) pods are installed, resulting in the Orbital configuration.

The 100 to 150 kW power platform assembly fixture containing the beam builder and solar blanket rolls is launched and berthed to the extendible strongback structure. The crane unfolds the jig and deploys the composite beam building module and the solar blanket rolls. Four longerons for the power platform have been fabricated and are being translated through the assembly fixture while the solar blanket roll is being deployed over the longerons. (Reference Figure 5-31) Following fabrication and assembly, the power platform is rotated into its operating position and the 38 kW power platform is released and returned to Orbiter program support. The SCB is now configured to proceed with construction of the remaining objective elements. To this point, the SCB configuration has been extensively Orbiter oriented with all crew activities within the Orbiter, including EVA activities, and has relied almost entirely on Orbiter provisions and accommodations.

5.4.4 Continuously Manned Space Construction Base

The transition from Shuttle-tended operations to continuously manned is efficiently achieved by the addition of the crew habitability module - the Construction Shack. This module provides the complete support for the seven crew members as well as supplants the support services of the Orbiter.

5.4.4.1 Selected Configuration

The selected strongback concept is shown in Figure 5-32 and its major characteristics in Table 5-8. The alternate concept with a telescoping construction fixture is shown in Figure 5-33. This concept does not have the operational flexibility of the strongback with its dual construction positions and three berthing or docking ports in the pressurized central tunnel. The alternate concept, the telescoping beam, is berthed to the SCM axial berthing port. This results in blocking the port and blocking a supplemental construction fixture

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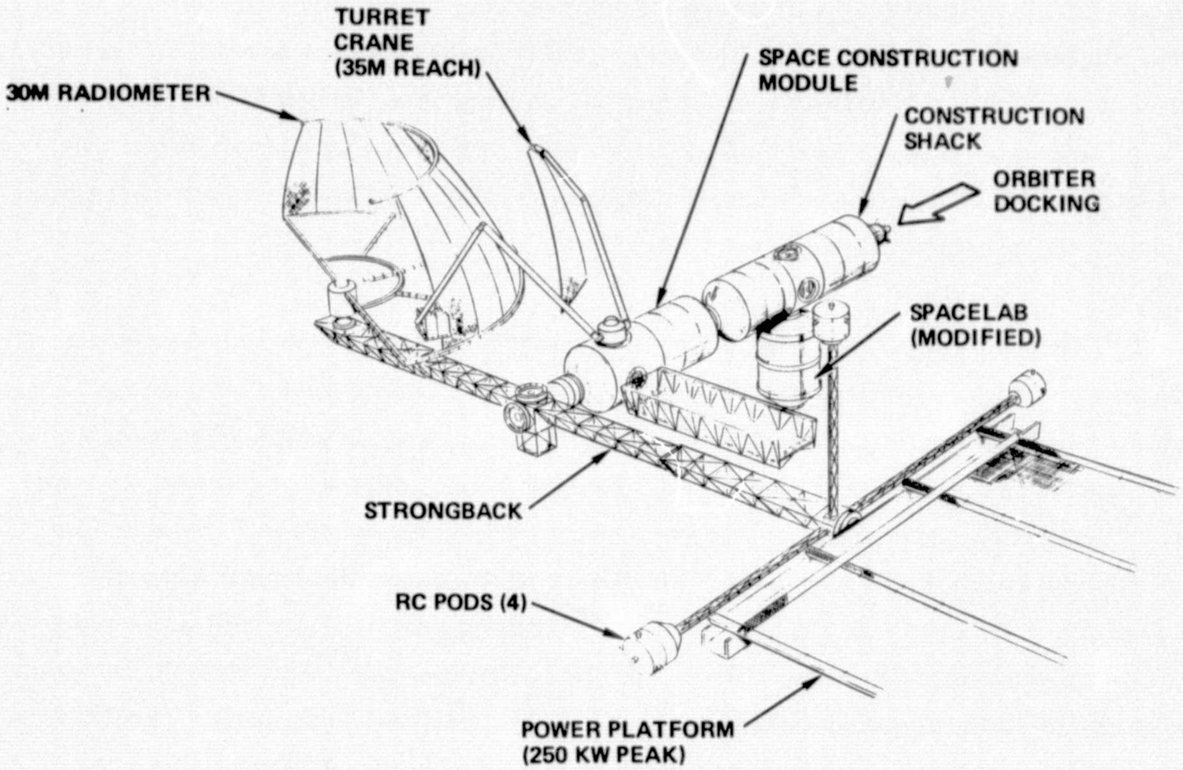

Figure 5-32. Space Processing Development Facility

Table 5-8

SPACE CONSTRUCTION BASE CHARACTERISTICS
(CONTINUOUSLY MANNED)

• Crew	- 4 to 7
• Shifts	- 1 or 2
• Modules	- Space Construction Module, Construction Shack
• Mission Equipment	- Orbiter Docking Adapter, Crane, Strongback, Power Platform RC Pods (4)
• Mass (kg)	- 42,273 (93,000 lbs)
• Pressurized Volume	- 316 m^3 (11,165 ft^3)
• Power (Bol) at Array	- 250 kW
• Array Area	- 2700 m^2
• Power (Bol) at Bus*	- 40 kW
• Module Heat Rejection	- 25.5 kW
• Radiator Area	- 210 m^2
• RCS Propellant - 90 days (kg)	- 9100 (20,000 lbs)

*100 kW average - limited to 40 kW by selected battery complement.

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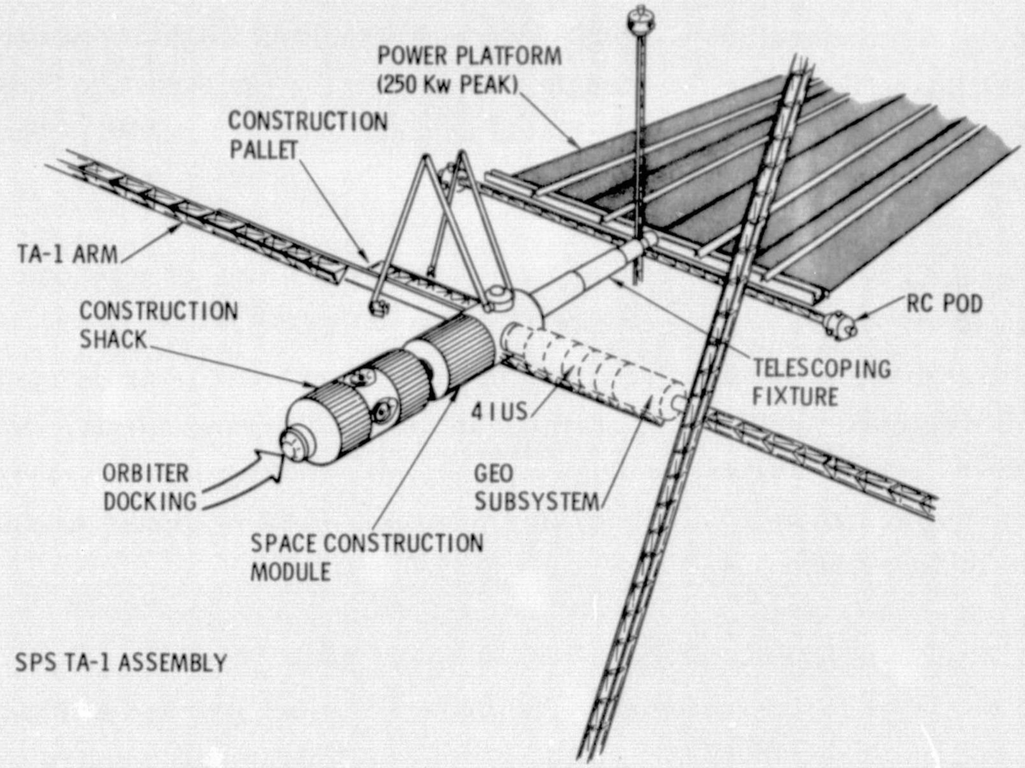

Figure 5-33. SCB — Telescoping Assembly Fixture Continuously Manned

for various objective elements berthed to a radial port. In addition, maintaining the required radiometer and MBL antenna flight test orientations places the module radiators in full sun.

The orbital flight conditions that the continuously manned SCB must meet are: (1) 60 to 120 days between Orbiter logistics and crew exchange visits, (2) 2 to 5 days of manned operational flight with the Orbiter docked and the largest objective element attached to the SCB, and (3) continuous support for a four-crewman single shift or a seven-crewman double shift.

In this mode, the Construction Shack provides the services and resources applied by the Orbiter as outlined in Subsection 5.4.3.1 for the Shuttle-tended SCB. Thus, the division of functional and operational requirements placed the crew support and SCB operations and control in the Construction Shack, and the space construction operations and control in the Space Construction Module. One key function which would be affected by the program plan is

the location of the EVA airlock. If the program approach is a direct move to continuously manned, then the EVA airlock should be considered for location in the Space Construction Module rather than the Construction Shack as in the Shuttle-tended SCB. The selected concept outboard layout is shown in Figure 5-34.

An increase in crew size is accommodated by the addition of a second Construction Shack either axially or radially berthed to the initial Construction Shack. Assuming continued growth, a berthing core module as defined in Part 2 is utilized. In all configurations and module arrangements, safety procedures, escape routes, emergency supplies, independent pressurized volumes, and alternate Orbiter docking positions were evaluated as summarized in Subsection 5.4.2.3.

All of the space-constructed objective elements from SPS Test Article 1 through the 100m torus radiometer satellite can be constructed and tested with the selected candidate SCB. The 100m radiometer will require the

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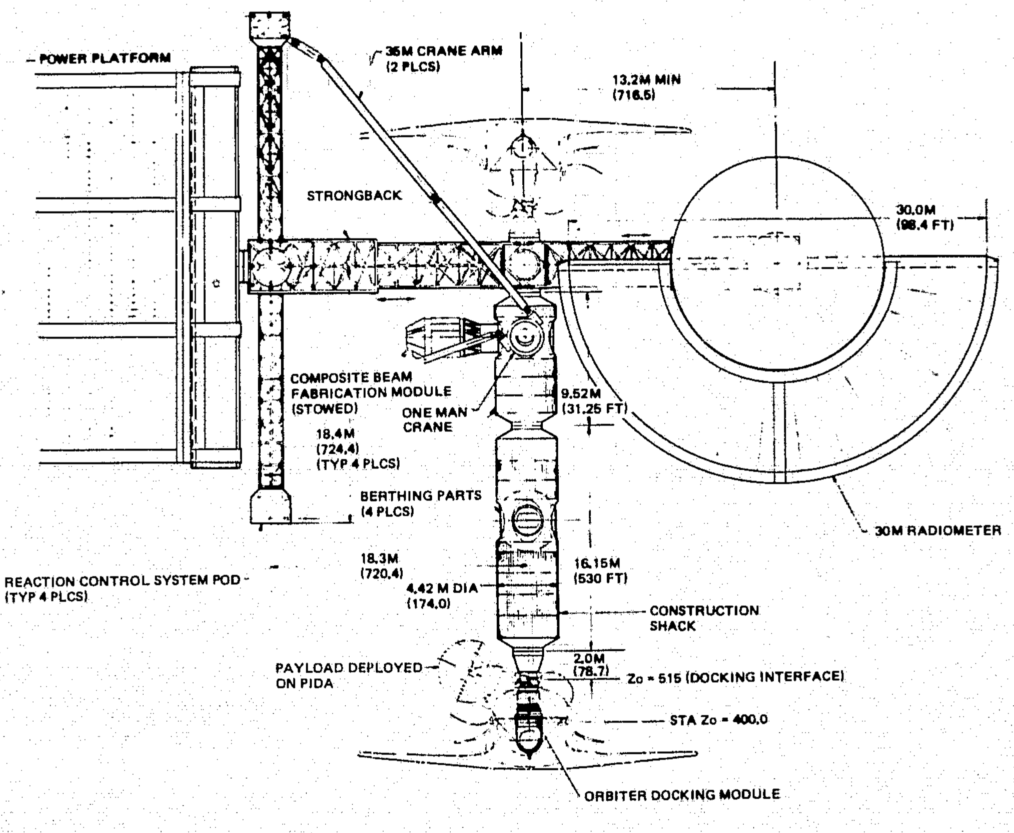


Figure 5-34. Space Construction Base Strongback Concept (X-Y Plance)

addition of a special folding fixture to the strongback for rotating the upper structure of the antenna to within reach of the 35m crane.

5.4.4.2 Orbital Buildup Sequence

Immediately following the completion of the power platform as defined in paragraph 5.4.3.2, the Construction Shack is launched into orbit. Following the docking operation between the Orbiter and the SCM, the CS is rotated from the cargo bay by the PIDA, and removed by the space crane and berthed to a radial berthing port on the SCM. Following transfer of crew and equipment, the Orbiter is undocked and the CS is relocated along the SCB X-axis. At this time the SCB is fully assembled, activated, manned, and capable of initiating routine operations in a continuously manned mode of operation without Orbiter support.

Then the TA-2 antenna pallet is launched and berthed to the strongback core structure and deployment is accomplished. Following its testing, the TA-2 antenna is collapsed, repackaged in the Orbiter cargo bay, and returned to earth.

To accomplish initial long-duration process definition and scientific research and development, the Space Processing Development Facility (SPDF) is brought up and berthed to the CS.

5.5 SUMMARY AND CONCLUSIONS

As summarized in Table 5-9, the Part 3 study results confirmed that a low-cost less-complex SCB concept definition is appropriate to initiate the continuously manned phase of manned space operations. This could be either a direct path to an all-up SCB which is continuously manned or an evolutionary growth path from the Shuttle-tended concept.

An important result regarding the configuration and number of modules is the reduction in the number of basic modules of the SCB from the Part 2 configurations. Through the reduction in subsystem redundancy, less consumable storage in the Construction Shack, and the acceptable decrease in certain volumetric allowances (crew quarters, EVA airlock, etc.), the basic SCB

Table 5-9

SUMMARY AND CONCLUSIONS

- Application of Orbiter subsystem hardware is practical and will reduce DDT&E costs significantly.
- Space Construction Module can effectively function in Shuttle-tended mode and accomplish major space construction projects.
- Construction Shack concept is viable approach to achieve low-cost capability for continuously manned operations.
- SCB configurations have been defined which meet all major operational requirements and simultaneously support both space construction and space processing/science.
- Attitude control of SCB including large space structures can be achieved with acceptable RCS propellant requirements.

concept consists of two modules and a power platform. This complement of modules/elements provides the necessary functional support which, in conjunction with construction equipment and specialized modules (e.g., space processing), can accomplish all of the study objective elements.

Section 6
MISSION OPERATIONS

During the course of Part 3 of the study, a detailed operations analysis of construction of the various mission hardware elements was performed. The results of this analysis along with considerations of attendant test activities such as those for the SPS program, provided a set of information with respect to what is required to support related on-orbit activities. These data then provided the basis for a set of requirements for specific subsystems such as the crane.

6.1 CONSTRUCTION OPERATIONS ANALYSIS

6.1.1 Analysis

A fixed work station construction system was utilized as the basis for the SCB design. The alternate in which a traveling work station is used was analyzed with respect to construction operations and compared with the fixed work station system. The results are reported in Section 6.4.3.

The mission hardware items described in Section 3 and illustrated in Figure 6-1 were designed in response to mission requirements in the areas of Satellite Power Systems (SPS), radiometry, and multiuser communication systems. In order to provide the required power level, bandwidth, frequency range, spatial coverage, etc., these mission hardware items, by necessity are quite large in size and thus must be constructed in orbit. A major facet of the study was then directed toward establishing the most cost effective method of constructing these items.

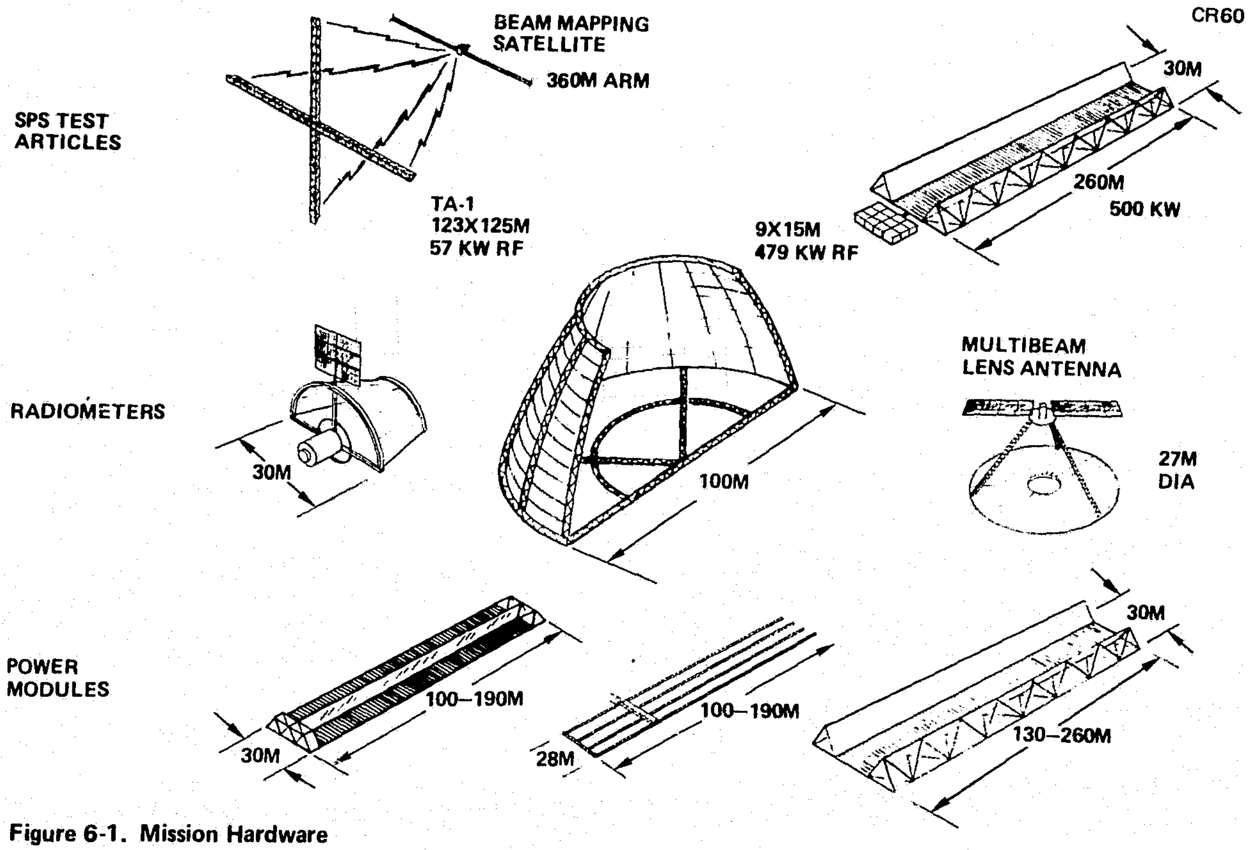


Figure 6-1. Mission Hardware

Analysis of construction of various mission hardware items led to the conclusion that the fixed work station concept probably is the most cost effective. Under this system, the part is either:

A. Assembled on a standoff which has a turntable which rotates the part past the work station as construction proceeds, or

B. "Extruded" by having the part fabricated continuously and/or assembled at the close-in work area. As each section is finished, it is pushed out and a new section constructed.

The procedure followed in analyzing construction was to first take the preliminary design layout for each item of mission hardware and packaging (for delivery) layouts and visualize how the part would be constructed. This was done in conjunction with the designer and the layouts modified where problems were identified. A detailed flow logic was then developed, with each step conceived to be a logical sequel to its immediate predecessor. As these logic flows were assembled, design modifications deemed desirable to simplify the construction process were proposed and, as before, coordinated with the designer. Upon achieving an acceptable flow, each event was

analyzed to determine how long it would take, how much EVA translation distance would be involved, the required crane reach, etc. These data were then compiled into timelines and the associated requirements summarized.

6.1.1.1 Test Article-1

In order to give an indication of the procedures and depth of analysis, analyses associated with construction of the SPS TA-1 are included herein.

Two different approaches for the construction of TA-1 were developed in the study. One approach, developed in Part 2 of the study, utilized on-orbit fabrication with automatic assembly. The second approach, developed in Part 3, utilized prefabricated beams deployed, in segments, on-orbit followed by electronics installation. This second approach was chosen for illustrative purposes (Figure 6-2).

The TA-1 consists of two long crossed arms, one 123m long and one 126m long, and is assembled in orbit using components fabricated on the ground. The arms are made up from truss beams approximately 15m long which are

CR60

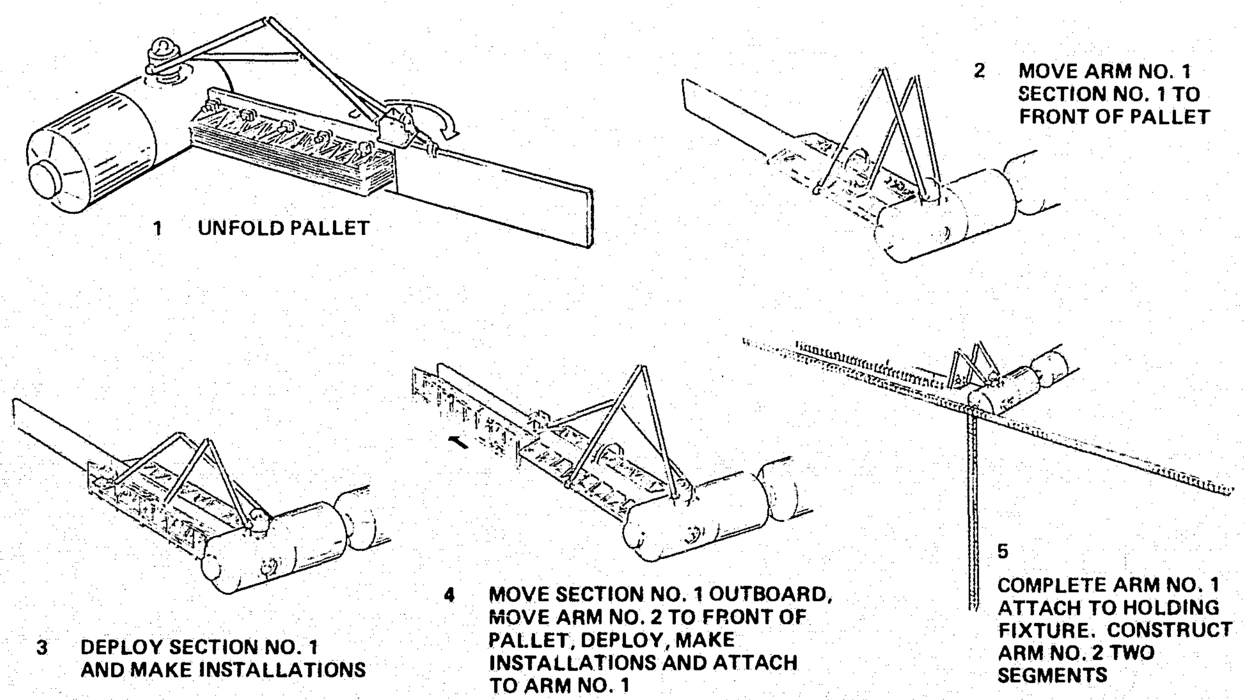


Figure 6-2. TA-1 Deployment

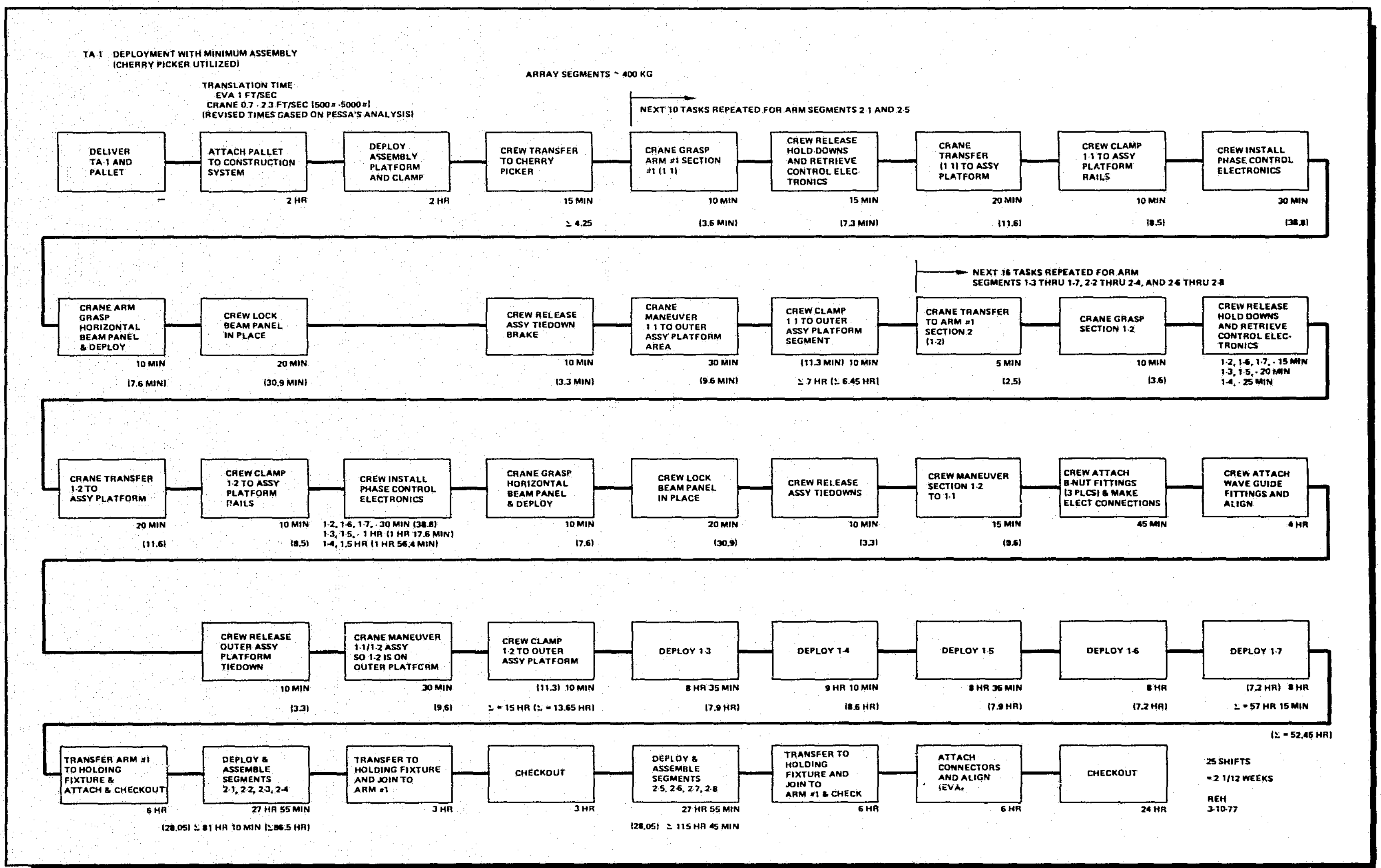


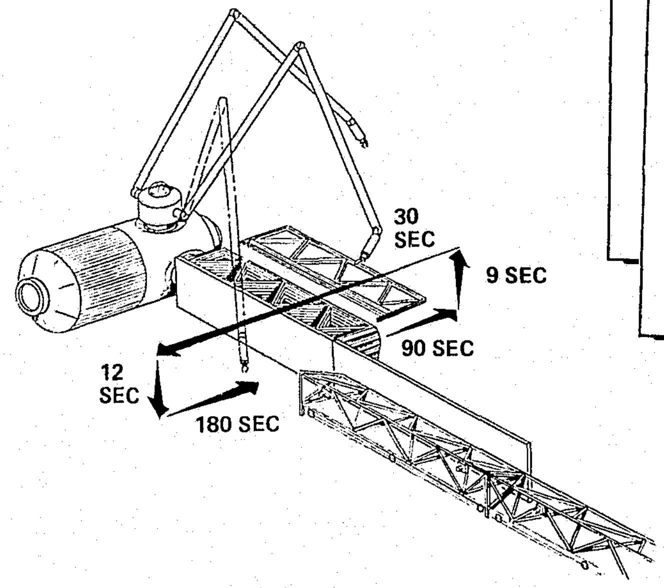
Figure 6-3. TA-1 Deployment Flow

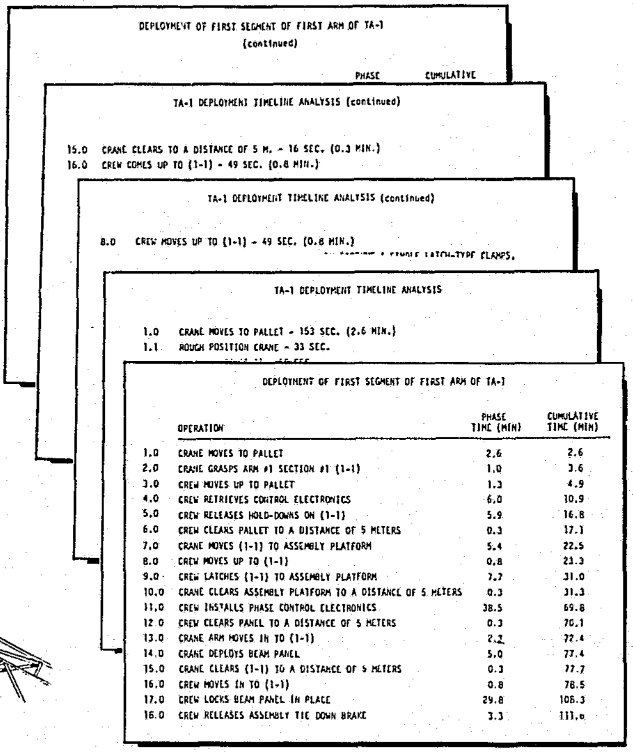
delivered in a collapsed configuration stored on a pallet. The pallet support structure has a double section which unfolds on-orbit, resulting in the pallet being over twice as long as the individual 15m beam segments stored on the pallet. The first collapsed beam segment is removed from the pallet and transferred to the other side where it is deployed and electronics installed. This erected 15m section is then moved to the outer portion of the unfolded pallet. The second beam section is then removed from the pallet and transferred to the other side where the preceding segment was originally deployed. This second segment is deployed, its electronics are installed, and it is joined to the first setment; then the combined segments are maneuvered outward until the second segment rests on the unfolded section of the pallet. The third segment is then removed, and the process keeps repeating until the arms of the antenna have been completed. As each arm is completed, it is installed on a separate standoff.

The sequence of deploying TA-1 beam segments and final assembly of the antenna was detailed in a flow diagram (Figure 6-3) and each event analyzed to determine such things as process times.

In the analysis of TA-1, individual activities were investigated in detail. As an example, the time required to deploy and assemble a given beam segment was analyzed to the nearest minute (and in some cases, seconds) as illustrated in Figure 6-4. The various operations involved in this sequence of events are found not only in subsequent activities associated with TA-1, but are found in simular form in other mission hardware construction sequences. As a result, the detailed analyses performed for TA-1 were useful in estimating process times for other mission hardware items.

The time required to construct mission hardware tends to be critical in making decisions with respect to the best construction methods, hardware configuration, etc. In establishing the time to perform various tasks, specific analyses were used where possible (e.g., use of crane dynamics data to compute transfer times); in others, Skylab experience was used. In some cases, direct estimates were made based on ground experience extrapolated to zero-g environment. The most time-consuming tasks were then





DEPLOYMENT OF FIRST SEGMENT OF FIRST ARM OF TA-1
(continued)

TA-1 DEPLOYMENT TIMELINE ANALYSIS (continued)

15.0 CRANE CLEARS TO A DISTANCE OF 5 M. - 16 SEC. (0.3 MIN.)
16.0 CREW COMES UP TO (1-1) - 49 SEC. (0.8 MIN.)

TA-1 DEPLOYMENT TIMELINE ANALYSIS (continued)

8.0 CREW MOVES UP TO (1-1) - 49 SEC. (0.8 MIN.)

TA-1 DEPLOYMENT TIMELINE ANALYSIS

1.0 CRANE MOVES TO PALLET - 153 SEC. (2.6 MIN.)
1.1 ROUGH POSITION CRANE - 33 SEC.

DEPLOYMENT OF FIRST SEGMENT OF FIRST ARM OF TA-1

	OPERATION	PHASE TIME (MIN)	CUMULATIVE TIME (MIN)
1.0	CRANE MOVES TO PALLET	2.6	2.6
2.0	CRANE GRASPS ARM #1 SECTION #1 (1-1)	1.0	3.6
3.0	CREW MOVES UP TO PALLET	1.3	4.9
4.0	CREW RETRIEVES CONTROL ELECTRONICS	6.0	10.9
5.0	CREW RELEASES HOLD-DOWNS ON (1-1)	5.9	16.8
6.0	CREW CLEARS PALLET TO A DISTANCE OF 5 METERS	0.3	17.1
7.0	CRANE MOVES (1-1) TO ASSEMBLY PLATFORM	5.4	22.5
8.0	CREW MOVES UP TO (1-1)	0.8	23.3
9.0	CREW LATCHES (1-1) TO ASSEMBLY PLATFORM	7.7	31.0
10.0	CRANE CLEARS ASSEMBLY PLATFORM TO A DISTANCE OF 5 METERS	0.3	31.3
11.0	CREW INSTALLS PHASE CONTROL ELECTRONICS	38.5	69.8
12.0	CREW CLEARS PANEL TO A DISTANCE OF 5 METERS	0.3	70.1
13.0	CRANE ARM MOVES IN TO (1-1)	2.2	72.4
14.0	CRANE DEPLOYS BEAM PANEL	5.0	77.4
15.0	CRANE CLEARS (1-1) TO A DISTANCE OF 5 METERS	0.3	77.7
16.0	CREW MOVES IN TO (1-1)	0.8	78.5
17.0	CREW LOCKS BEAM PANEL IN PLACE	29.8	108.3
16.0	CREW RELEASES ASSEMBLY TIE DOWN BRAKE	3.3	111.6

Figure 6-4. Beam Assembly Transfer

identified and sensitivity analyses performed to determine the criticality of our analyses or estimates. With these critical areas identified, the time estimates were considered in greater detail and revised as appropriate. For TA-1 the most time-consuming tasks (as estimated) were electronics assembly and mechanical alignment (Figure 6-5). Clearly, these areas are ones where future analyses should concentrate.

As a result of the construction analysis, the timeline of TA-1 construction was developed (Figure 6-6). The actual construction takes only a little over two weeks (assuming two shifts a day) followed by a 2-week checkout. This results in about a 1-month period from launch of the TA-1 pallet to completion of initial checkout. It should be pointed out that this is a success-oriented schedule with no contingency time for rework, repair, low time estimates, etc. Contingency allowances are discussed later.

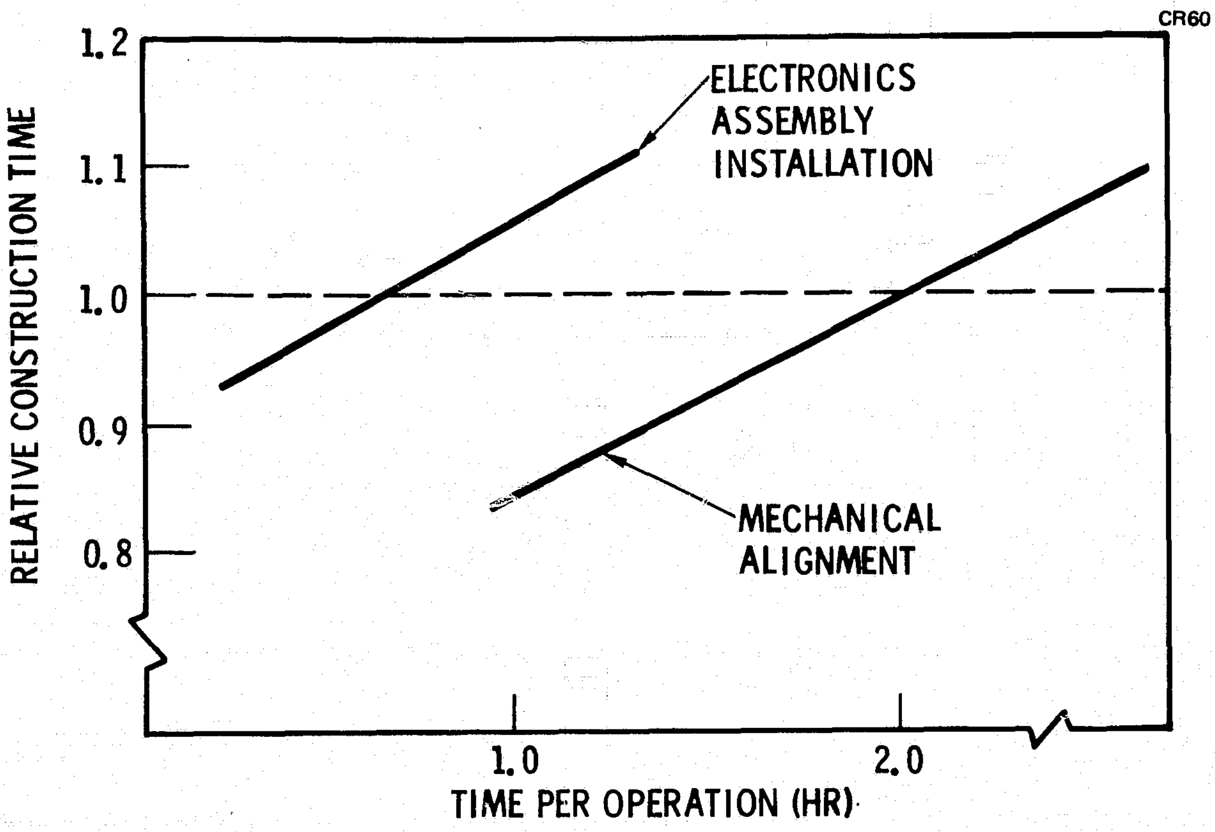


Figure 6-5. Crew Task Sensitivities for TA-1 (Typical)

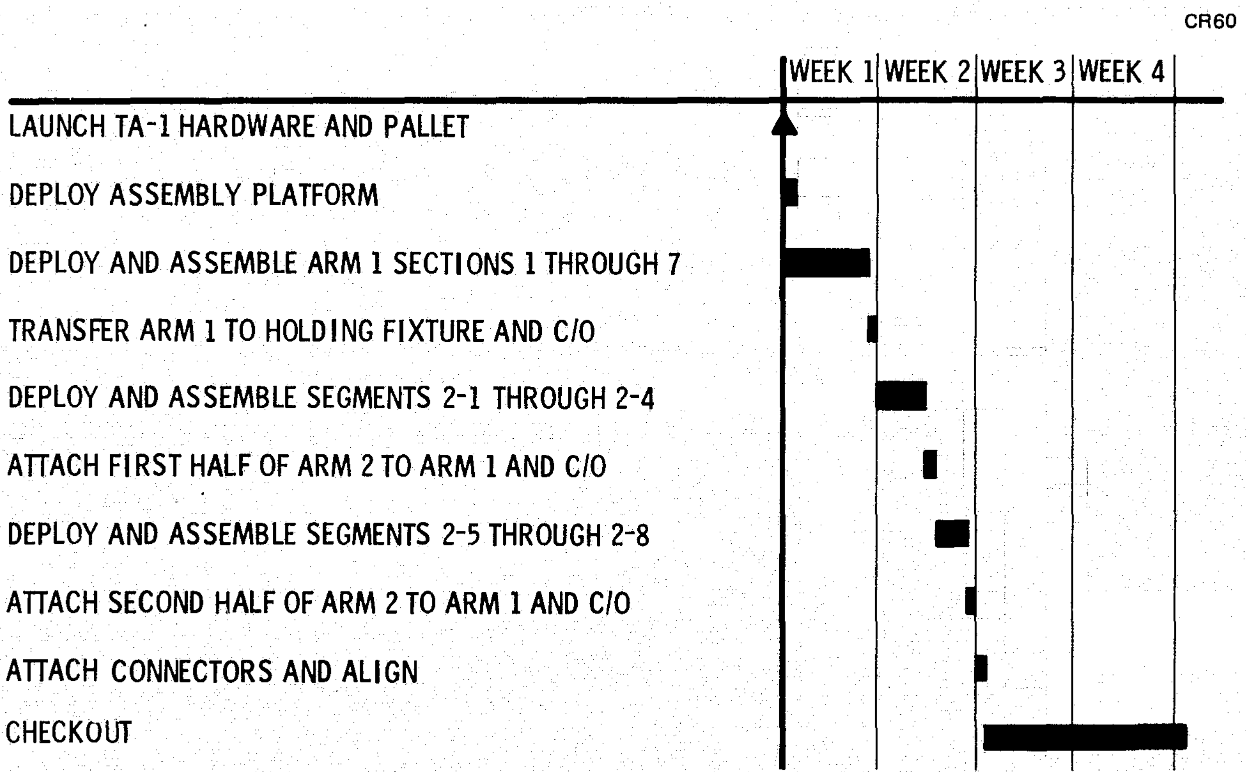


Figure 6-6. TA-1 Deployment Schedule

6.1.1.2 Large Power Platform

The large power platform needed to satisfy the requirements discussed in Section 3.1 was investigated during Part 3 of the study. Three construction techniques (Figure 6-7) were utilized in design and their operations analyzed. The first approach involves a continuous fabrication technique involving on-orbit construction of composite longerons. Final assembly and installation of solar array blankets is done by EVA. The second approach uses EVA for both assembly of the structure, using prefabricated truss members joined on-orbit, and installation of solar array blankets and reflectors. The third approach brings the power platform up in folded segments having ground-installed solar array blankets and reflectors. The segments are unfolded on-orbit using the crane, and sections are joined by EVA.

Detailed flows for each technique were derived and sensitivity analyses performed to identify critical operations for additional study. Figure 6-8 is an example of sensitivities associated with the power platform concept involving on-orbit fabrication.

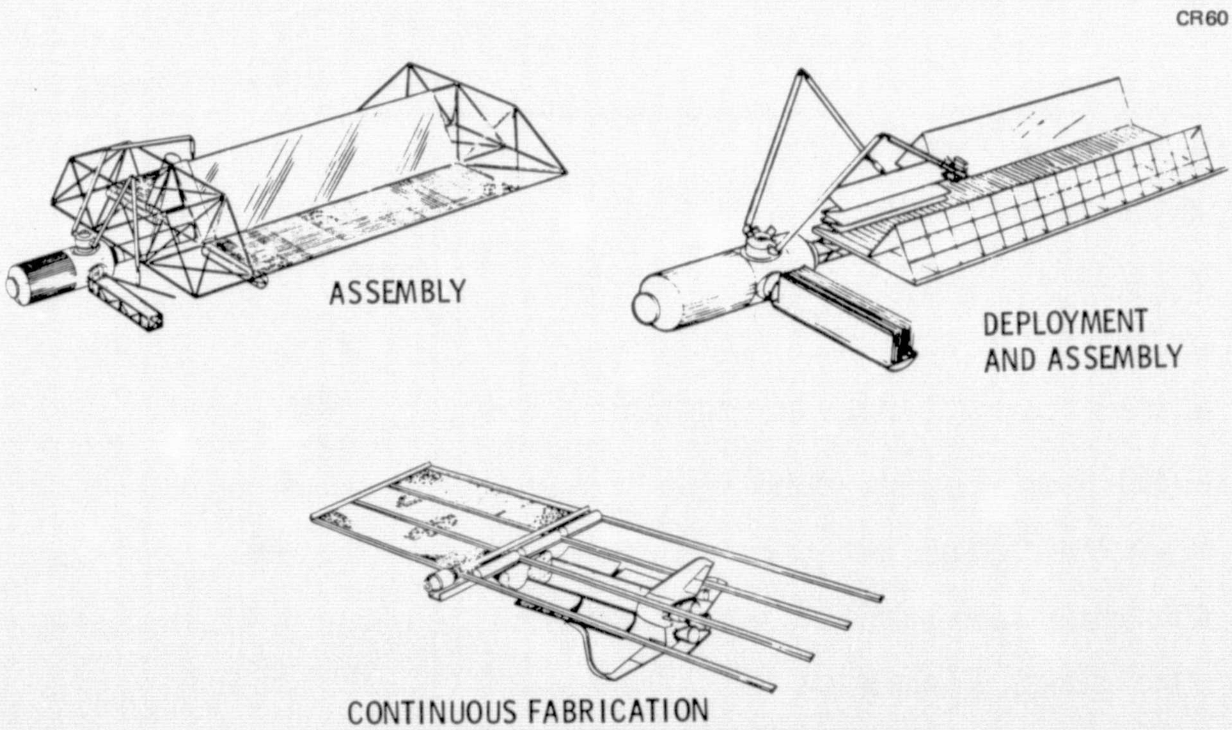


Figure 6-7. Power Platform Construction Concepts

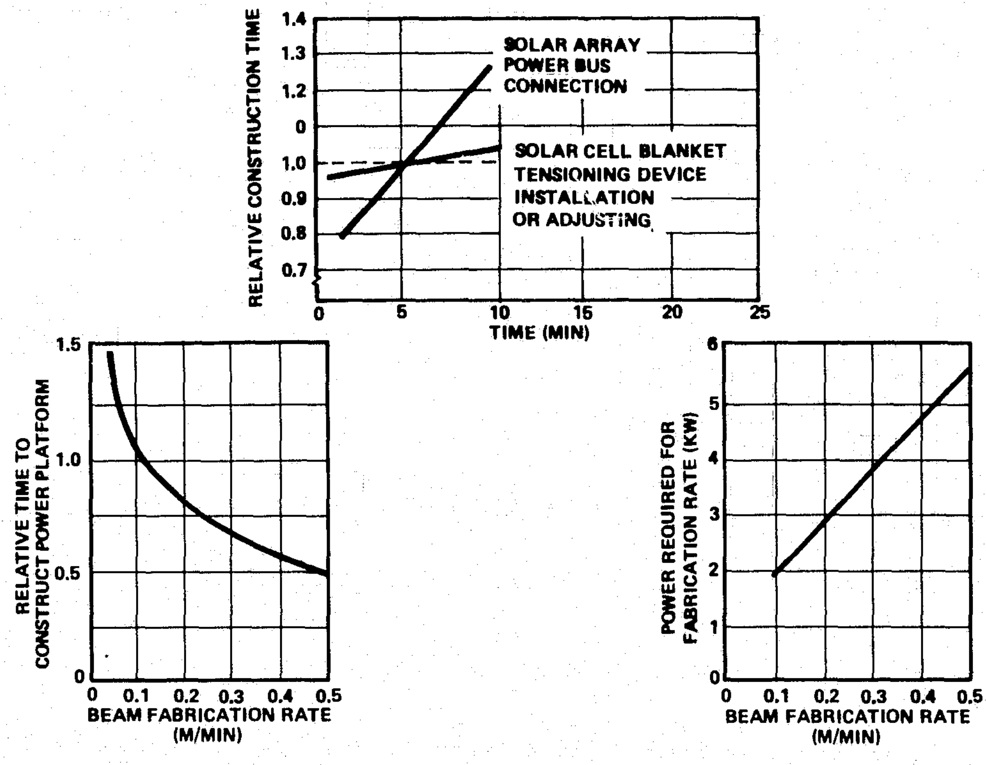


Figure 6-8. Rate Sensitivities – Continuous Fabrication of the Large Power Platform

6.1.1.3 100 Meter Radiometer

As a result of Part 2, inclusion of variously sized radiometers to cover different wave lengths was indicated and, accordingly, a 100m radiometer concept was developed. It was determined that the best approach for constructing this large item was via on-orbit assembly. The steps for doing this were derived as noted in Section 4. As before, sensitivity analyses were run to identify critical tasks requiring further study (see Figure 6-9). As an example, the original estimate for beam deployment and joining was 2 hours and 20 minutes, a more detailed analysis resulted in reducing this time to 1 hour and 8 minutes.

6.1.2 Construction System Requirements

Using the previously discussed detailed flows, timelines for the various mission hardware items were developed on a "success" basis. Experience in manufacturing reveals that unexpected problems invariably arise the first time a part is constructed, and allowance for such must be made.

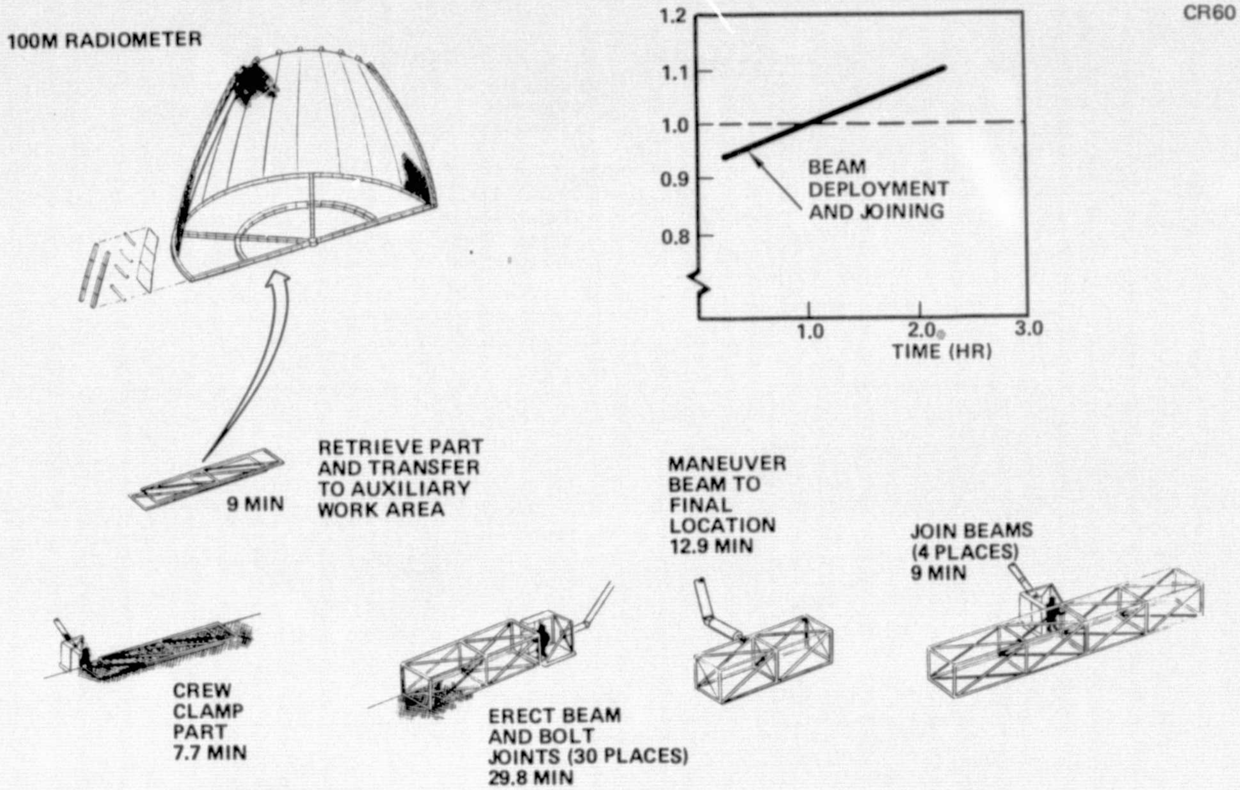


Figure 6-9. 100m Radiometer Assembly

Also, JSC document "Application of Skylab Workday Analysis to Future Programs", JSC 12856, May 1977 states; "Zero-g can be a friend or a foe, and accurately timelining a task not previously performed in zero-g or simulated zero-g tends to be very difficult. Even then there may be decided variations in the techniques and approaches used by different crewmembers, with accompanying differences in performance time. The unexpected should be expected when developing timelines for inflight activities, and slack time and fall-back positions should be maintained to allow for either contingencies or just ordinary adaptation to the environment."

In estimating construction times (Table 6-1) as was done in the study, a reasonable assumption is that in the time spans noted, a smooth running assembly line would be achieved at about the eighth unit. Using this assumption and a learning curve value of 85 percent (based on Skylab experience), the T1 (first article) construction times for each item of mission hardware should be increased by about 63 percent over that estimated. Adding the time for checkout of the hardware along with test operations results in the time spans summarized in Table 6-2.

Table 6-1

CONSTRUCTION SYSTEM REQUIREMENTS

Construction Item	Construction Time (T)* Shifts	Shuttle Hardware Delivery Launches	Cherry Picker Plat-form	Crane (Reach-m)	Turn-Table	Stand-off (Length-m)	Auxi-liary Work Area	Special Tools
TA-1 Deploy/Assembly	26	1	X	30	X	30	X	
TA-1 Fabrication Automatic Assembly	66	2	X	20	X			Tube/Truss Assembly
TA-2 Deploy/Assembly	34	3	X	25		17		
TA-2 Fabrication Automatic Assembly	69	5	X	35				Tube/Truss Cap Maker Auto Beam Assembly
MBL Assembly	72	3	X	30	X	15		
30M Radiometer Assembly	62.5	1	X	25	X	17		
100M Radiometer Assembly	175	6	X	30	X	52 (Telescoping)	X	
250-kW Power Platform Deployment	18	3	X	25		17		
250-kW Power Platform Assembly	22	1	X	20		24 (Telescoping)		
250-kW Platform Fabrication	32	1	X	30				Composite Beam Maker (1m)
250-kW Platform Fabrication Automatic Assembly	36	3	X	35				Cap Maker Auto Beam Assembly

*Does not include time for contigencies, test or tool certification

Table 6-2

TOTAL OPERATIONS TIME

Item	Construction Time (days)*	Contin-gency (days)*	Checkout (days)**	Experiment Operations (days)**	Total Calendar (days)
TA-1 Deploy/ Assembly	14	9	15	270	308
TA-1 Fabricate with Automatic Assembly	38	21†	15	270	344
TA-2 Deploy/ Assembly	19	12	30	360	421
TA-2 Fabricate with Automatic Assembly	40	24†	30	360	454
Multibeam Lens Antenna Assembly	42	26	24	---	92
30M Radiometer Assembly	37	23	18	---	78
100M Radiometer Assembly	104	66	18	---	188
250-kW Power Platform Deployment	10	6	10	---	26
250-kW Power Platform Deployment	12	8	10	---	30
250-kW Power Platform Deployment	18	11	30	---	59
250-kW Power Platform Fabricate with Automatic Assembly	20	10	30	---	60

*Assumes 2-shift, 6-day workweek
**Assumes 3-shift, 6-day workweek
†Direct estimates

Analysis of the events associated with construction of each item of mission hardware revealed many requirements for construction equipment and special tools and fixtures. In keeping with the fixed work station construction concept, key items of construction equipment are a cherry picker platform and a crane. The cherry picker platform (Figure 6-10) supports two EVA crewman during construction and is mounted on the end of one arm of the crane. Crane controls are located on the platform, and thus the EVA crewmen can maneuver themselves about the part. The other arm of the crane is used to transfer and position parts. A standoff having a telescoping capability and a turntable which can maneuver the mission hardware item under construction to the work station also is needed. Considerations of the relative positioning capabilities needed for the different mission hardware items resulted in a requirement that the crane have a reach of 35 meters with the variable length standoff capable of being extended up to 52 meters. The utilization of the two-arm crane is a basic element of the fixed work station concept and thus was studied in some detail. The possible functions that a crane can perform (Table 6-3) were identified and

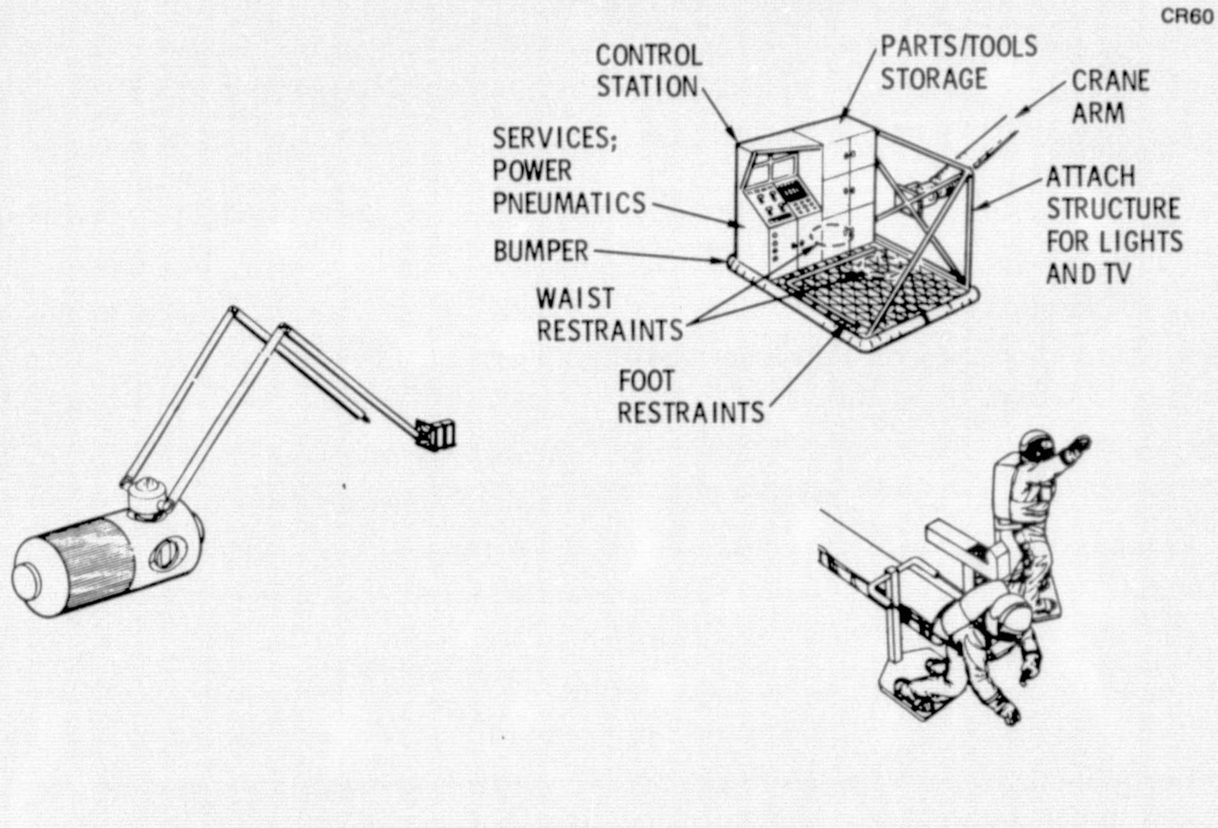


Figure 6-10. Cherry Picker Platform (EVA) Concepts

Table 6-3

POTENTIAL MANIPULATOR FUNCTIONS
FOR CONSTRUCTION IN SPACE

- Transfer of Parts and Assemblies
  - Pallets from Orbiter to construction site Docked Orbiter

    Orbiter flying information
  - Parts/assemblies from storage to work station
  - Movement of completed assemblies to storage
- Assembly Operations
  - Precision placement of parts for joining
  - Deployment of assemblies
  - Remote fastening, making connections, etc.
- EVA Support
  - Transfer of men to work site
  - Support of mobile work station
- Remote Handling of High-Pressure Vessels
- Emergency/Repair Operations
  - Prying, bending, cutting, etc.
  - Retrieval (unattached parts, stranded crewmen etc.)

considered in developing the requirements for the crane system in terms of force, reach, degrees of freedom, operational modes, etc. In general, the crane has been conceived to be a very utilitarian device capable of supporting a broad spectrum of manned activities on orbit.

One of the key functions of the crane is to maneuver parts and assemblies about the SCB and to position them for final joining, attachment, or release The parts and assemblies that are involved range from relatively small, lightweight struts all the way up to very large items of mission hardware (see Figure 6-11). Thus, the crane must be capable of handling, with precision, a broad range of weights and inertias. The crane has to position these parts; however, final positioning (the last few centimeters) is probably best done by hand with the crane merely providing damping. Using the crane to deploy parts also is of value, though timeline analysis indicates this to be

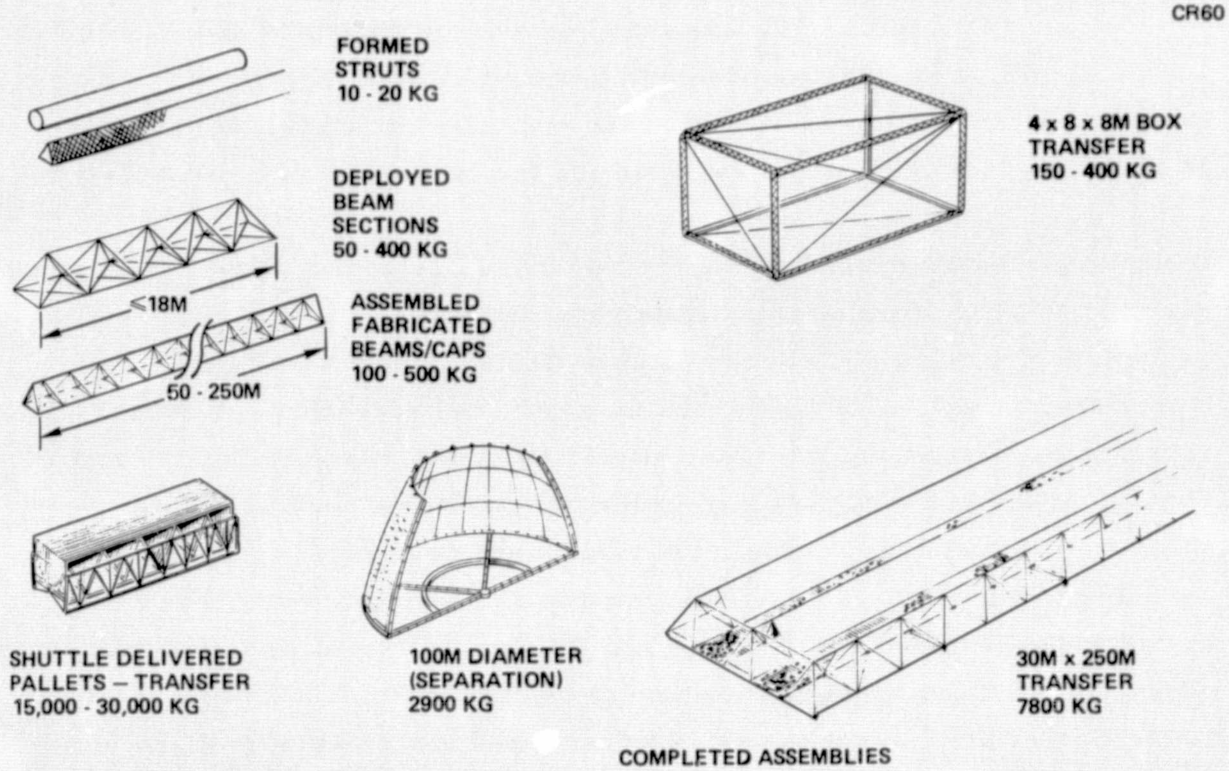


Figure 6-11. Typical Parts/Assemblies

relatively slow compared to having the parts self-deployed. Utilization of the crane for high precision tasks such as inserting pins or positioning an automatic tool imposes extreme positioning accuracy requirements which may be very costly to satisfy and thus such operations are probably not suitable for the crane.

To use the crane to position parts and maneuver the cherry picker the number of degrees of freedom needed were evaluated. First, to transfer a part to a given location, a minimum of three degrees of freedom are required (forward and back, up and down, and side motion). Using an articulated arm crane with shoulder pitch and yaw and elbow pitch provides the necessary three degrees of freedom. However, with only three degrees of freedom, there is only one possible conbination of shoulder yaw and pitch and elbow pitch angles associated with reaching a given point in space (this also holds for other three-degrees-of-freedom crane configurations involving degrees of freedom provided by such things as rails and telescoping arms). As a result, there will be only one possible spatial orientation of the crane to reach that point. If there is an obstacle, then the crane cannot reach the desired position unless a fourth degree of freedom is added. For the articulated arm crane, this is best provided by a roll degree of freedom in the

upper arm. With this, there are multiple arm orientations possible to reach a given point. For final positioning, three additional degrees of freedom (pitch, yaw and roll), are needed at the end effecter, resulting in a minimum of seven degrees of freedom required for the crane arm (Figure 6-12).

With the geometry requirements for the crane developed, it was then necessary to establish basic performance requirements. One key requirement is crane translation rate. For very heavy items, such as an SCB module, translation rates can be (and probably should be) very slow. However, in construction activities, the crane should be able to maneuver parts and the cherry picker more quickly. In order to establish a desirable rate, sensitivity analyses of crane translation rates were performed (Figure 6-13) considering the various mission hardware construction jobs. The results of the analysis revealed that average translation rates of 0.25 to 0.5 m/sec are desirable. Slower rates tend to have a significant impact on construction time; faster rates do not materially decrease construction time, but could significantly influence cost.

Crane dynamics were simulated to determine structural responses to commands and establish tip force requirements. The period of oscillation of the crane is a strong function of the load mass having long periods (greater than 10 sec) for masses greater than 4,500 kg (10,000 lb) weight (Figure 6-14). Greater arm masses (increasing gage thickness of the arm) help in reducing the period. This oscillation can present problems both in positioning parts and to crewmen in a cherry picker. If damping is not provided in the system, first-mode bending responses to step commands will be underdamped. The addition of lateral velocity damping using an integrating accelerometer on the arm considerably improves the damping response. The best command response is achieved by using a ramp input or rate command system in conjunction with an arm having a tip force of 220N(50 lbs). The commanded rate is low (0.24 m/sec) and the resultant lateral velocity is only slightly higher in the first few seconds. This approach affords the advantage of having less kinetic energy in the system (less chance of damage with a servo system failure) and lower tip force requirements. Higher mode damping can be achieved, if necessary with additional lateral velocity meters stationed along the arm.

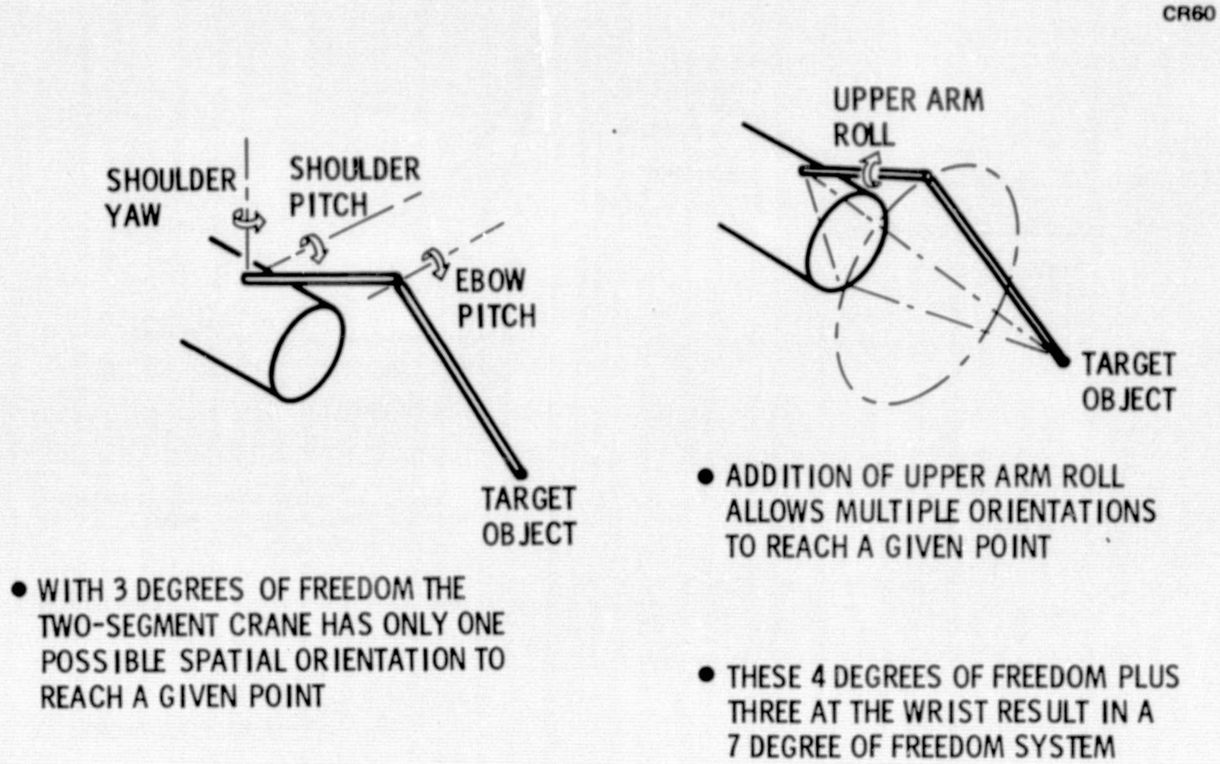


Figure 6-12. Arm Access Around an Obstacle

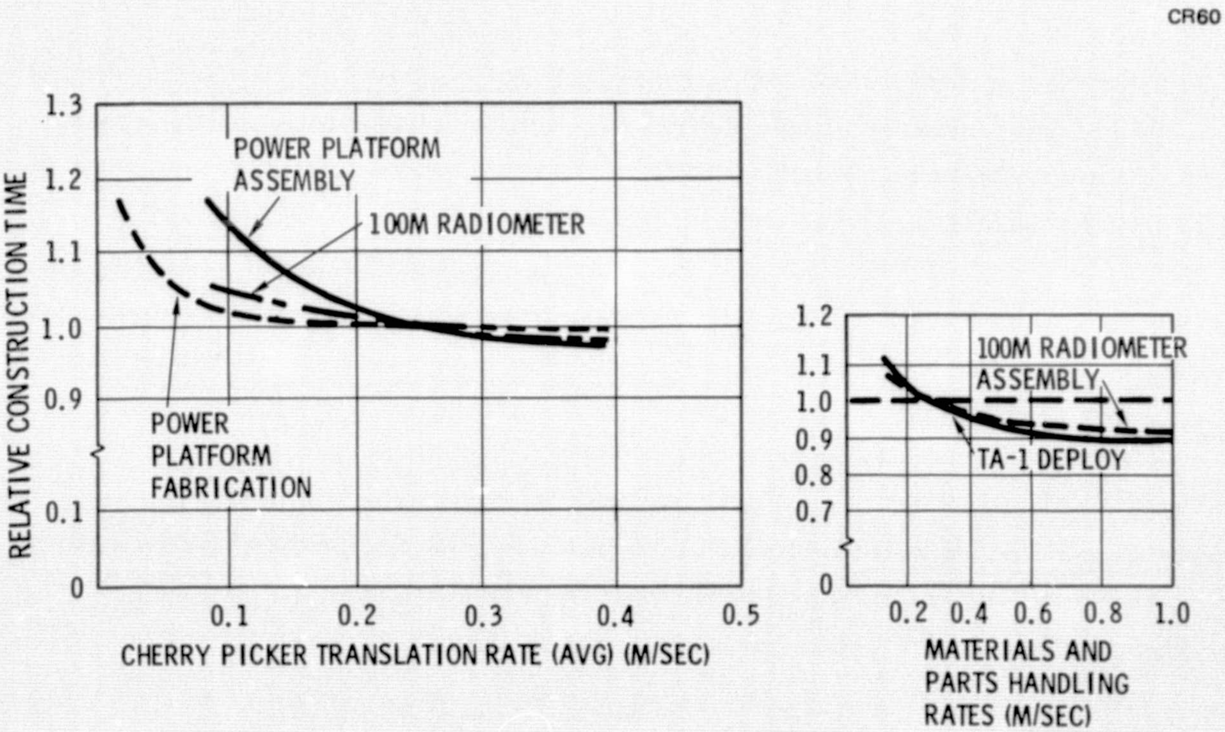


Figure 6-13. Crane Translation Rate Sensitivity (Normalized)

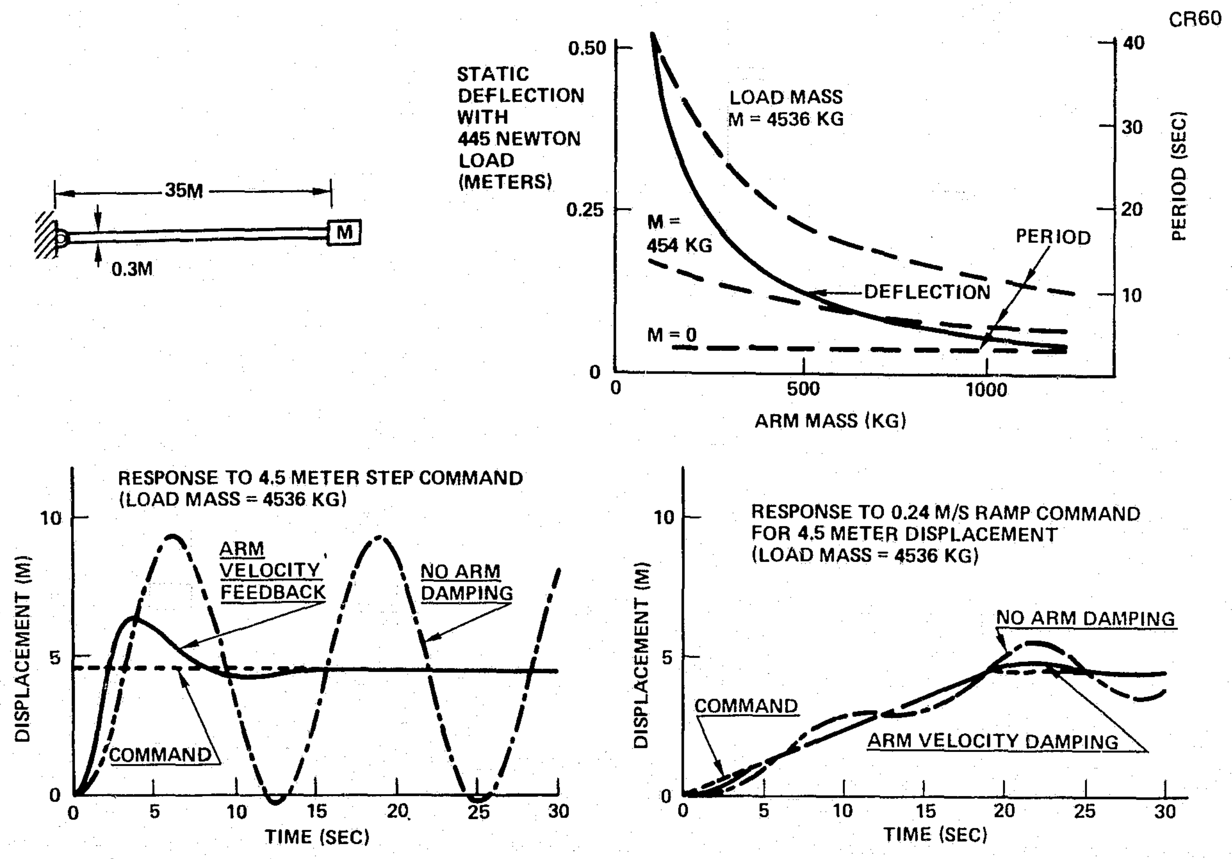


Figure 6-14. Crane Characteristics

The results of design and performance analysis of the crane can be stated as a set of requirements (Table 6-4). The crane is used to both maneuver parts/assemblies and berth modules. The necessary reach for each of two arms is 35m and an average rate capability of 0.25 to 0.5 m/sec for construction tasks which require manipulating items up to about 1,500 kg in weight. The system also needs software for collision avoidance and a rate feedback system for damping.

6.1.3 EVA Considerations

In the analysis of the construction of the various mission hardware items, it was found that significant portions of the work required EVA crewmen. Thus, extensive accommodation of EVA work has to be included in planning. This extensive use of EVA was not restricted to those hardware items involving

Table 6-4

CRANE REQUIREMENTS

- Able to Manipulate Assemblies and Berth Modules up to 15,000 KG
- Able to Manipulate and Position Parts up to 1500 KG
- 35 Meter Reach and General Grasping Capability
- Degrees of Freedom:
  - Wrist joint (pitch, yaw, roll)
  - Shoulder joint (pitch, yaw° roll)
  - Elbow joint (pitch)
- Arm Tip Force Capability of 220 N
- 0.5 m/sec Max Rate with no Load
- Arms Operated Independently
- Auxiliary Control from Cherry Picker Platform
- Vernier Positioning Mode Using External Force (Astronaut) at Tip
- Unobstructed View for Crane Operator
- Collision Avoidance Software and/or Max Torque Override
- Automatic Joint Lock in Case of Joint Motor Failure
- Damping Provided by Rate Feedback System

on-orbit assembly. For jobs in which fabrication is done on orbit, tool setup and EVA assembly operations require the overwhelming majority of the time.

The EVA system requirements are driven primarily by EVA construction operations and secondarily by EVA maintenance and emergency rescue operations. The following EVA system requirements were derived from evaluation and expansion of the Space Station Design Guidelines and Criteria (JSC-11867) and from the scenarios for space construction activities developed during this study.

The EVA system must:

- Accommodate single or multishift construction operations.
- Support two-man EVA construction crews for work shifts up to six hours in duration.
- Accommodate daily EVA construction operations, during both light and dark orbital periods, for as many as six days a week.
- Provide protection for construction crewmen during EVA by means of a pressure enclosure, breathing atmosphere, contamination and temperature control, emergency oxygen supply, visual and communications monitoring, and rescue if necessary.
- Provide safe translation for EVA crewmen to and from the work area and within the work area.
- Provide restraint while at the work area.
- Permit EVA crewmen to perform all required manual construction operations with minimum loss of dexterity and mobility and with minimum fatigue.
- Minimize the number of EVA suits and suit parts required.
- Minimize use of expendables.
- Minimize time required for pre- and post-EVA activities.
- Provide rapid suit turnaround time between EVA sojourns by minimizing recharge, drying, component replacement, and refurbish times.
- Provide emergency depressurization protection and rescue for all crew members.

To satisfy the above requirements the EVA system must provide the necessary hardware and expendables, in sufficient quantities, and in optimum locations. The EVA system defined for the SCB consists of the following elements as part of the Crew and Habitability Subsystem description: Crew and Habitability Subsystem description:

A. Pressure Suits (with attached life support systems) — The suit to be used is the Shuttle EMU described in JSC 10615 "Shuttle EVA Description and Design Criteria." In general, one suit is required for each crewman assigned as a construction worker, with additional suits required for other key crew members.

B. Personnel Rescue Systems (PRS) – 36 in. diameter sphere for rescue of crewman by a pressure-suited colleague. One PRS required for each crewman who does not have a suit or whose suit may be located where it is not available in an emergency.

C. Portable Oxygen Systems (POS) – Oxygen masks which can be used independently for short periods or connected to a vehicle oxygen system for longer uses (e.g., for prebreathing if required).

D. EVA Translation and Restraint – Includes handrails, tethers, SCB crane or Orbiter RMS end effecters, foot and waist restraints, portable and nonportable EVA work stations, and Manned Maneuvering Units (MMU's).

E. Airlocks – Minimum volume airlocks with capability for pumpdown of airlock atmosphere.

F. Suit Donning/Doffing Stations – Located outside of the airlock to minimize required airlock volume. They will serve also as suit stowage stations.

G. Suit Recharge Stations – Located outside of airlock to minimize airlock volume. They will provide expendabel replenishment, battery recharging, suit drying, and suit cooling pre- and post-EVA.

H. Expendables and expendable storage.

The EVA groundrules were developed to guide design and operation of the EVA system for the Space Construction Base. These guidelines are contained in Appendices to JSC-11867 "Space Construction Base Design Guidelines and Criteria" and are summarized below. They include guidelines categorized under the following headings: Duration, EVA Airlocks, EVA Suits, EVA Translation, EVA Mobility and Restraint, EVA Safety, and Pre/Post-EVA.

Duration – Duration groundrules specify a maximum continuous EVA duration of six hours, maximum of six hours EVA per crewman per 24-hour day, maximum of six successive days of EVA per crewman, capability to perform EVA during both light and dark orbital periods and during periods of no ground station coverage, and provision for restricted EVA during passage through the South Atlantic Anomaly to limit radiation exposure.

Airlock — Airlock groundrules provide that the airlock through which construction workers egress will be sized for a minimum three-man occupancy, will be depressurized by pumpdown (to approximately 0.5 psia) to the SCB cabin, and will be capable of rapid (approximately one minute) repressurization.

EVA Suit — EVA suit groundrules specify suit pressure as approximately 4 psia and a prebreathing period prior to EVA of three hours. Suit stowage, donning/doffing, suit checkout, recharging, drying, and repair will be done adjacent to the EVA airlock. Suits for individual crewmen will be assembled and fitted preflight, but will be capable of inflight adjustment for use by other crewmen. Suits will provide for in-suit liquid nourishment, urine collection during EVA, and a 30 minute emergency oxygen supply. Suits will sustain a maximum metabolic energy expenditure of 7000 Btu (average 1000 Btu/hr, up to 1600 Btu/hr for one hour, and 2000 Btu/hr for periods not exceeding 15 minutes). Suits can be used after a recharging/drying period of not more than 14 hours, but in an emergency can be used within 1.5 hours after doffing. Suits will have independent life support systems (not umbilical supported).

Translation — Translation groundrules provide that translation will be by hand rails, handholds, and/or with crewman supported on end of crane or remote manipulator and that average velocity will be assumed to be 0.8 fps (though crew translation in excess of 2.0 fps can safely be attained).

Mobility and Restraint — These groundrules dictate generous use of locomotion and restraint devices in external SCB design and provide for portable EVA work stations for seldom used work locations.

Safety — Safety groundrules specify return of EVA crewmen to a safe environment within 30 minutes, a "buddy" system for construction crews, and backup of crewman using MMU by using a second MMU. They provide for continuous voice contact between EVA crewmen and between crewmen and the control center, and for visual surveillance of EVA crewmen from the SCB at all times. No EVA work will be performed in an unrestrained condition, and work areas and translation routes will be sufficiently illuminated.

Pre/Post-EVA — These groundrules specify three hours prebreathing and that prebreathing can be initiated with portable oxygen masks used independently and/or plugged into conveniently placed outlets. Though suit donning can be done inside an airlock, suits will be stowed outside, and post-EVA recharging and drying will be performed outside of the airlock.

6.1.4 Radiation Considerations

The potential crew radiation dose was calculated to determine its effect on system design and capabilities. The dose received during EVA and while residing in a module was parametrically analyzed. In summary, the Shuttle EVA suit and a module designed for pressure, meteoroid, thermal, etc, is sufficient to provide adequate protection for low inclination (28.5 degree) missions up to altitudes of about 560 km. Above that altitude shield additions would be required. At higher inclinations (55 degrees) additional EVA suit protection is required, the module wall thickness must be increased, and a biowell (for solarflare events) must be provided.

6.1.4.1 Radiation Environment/Allowable Dose

The environment models used were: trapped electrons — AE-5 and AE-7; trapped protons AP-5, AP-6, AP-6 extrapolated, and AP-7; and solar cosmic rays — November 12, 1960 flare. The trapped radiation models were obtained from the GSFC Data Center and analyzed on MDAC computers.

The allowable dose limits used are shown in Table 6-5. They were obtained from 1970 NAS radiation guidelines.

6.1.4.2 Dose Analysis

The radiation dose received inside a typical module by each body organ was calculated. The skin dose was found to be the most critical since it was nearer the allowable and is the most difficult to shield. Figure 6-15 shows the daily skin dose received as a function of orbit inclination, altitude, and module cylinder wall thickness (the ends were assumed attached to other modules). For a typical wall thickness design of 0.1 in. (as designed by loads, pressure, meteoroid penetration, and thermal characteristics), the skin dose received at 28.5 degrees is well below the allowable in the 400 to 500 km altitude range (approximately 60 percent of the allowable dose). At

Table 6-5

ALLOWABLE DOSE LIMITS

	Primary Ref. Risk	Ancillary Reference Risks		
	(5 cm)	Base Marrow (5 cm)	Skin (0.1 mm)	Lens & Eye (3 mm)
1-year average daily rate		0.2	0.6	0.3
30-day maximum		25	75	37
Quarterly maximum*		35	105	52
Yearly limit		75	225	112
Career limit	400	400	1200	600

*May be allowed for two consecutive quarters followed by 6-month restriction to stay within yearly limit.

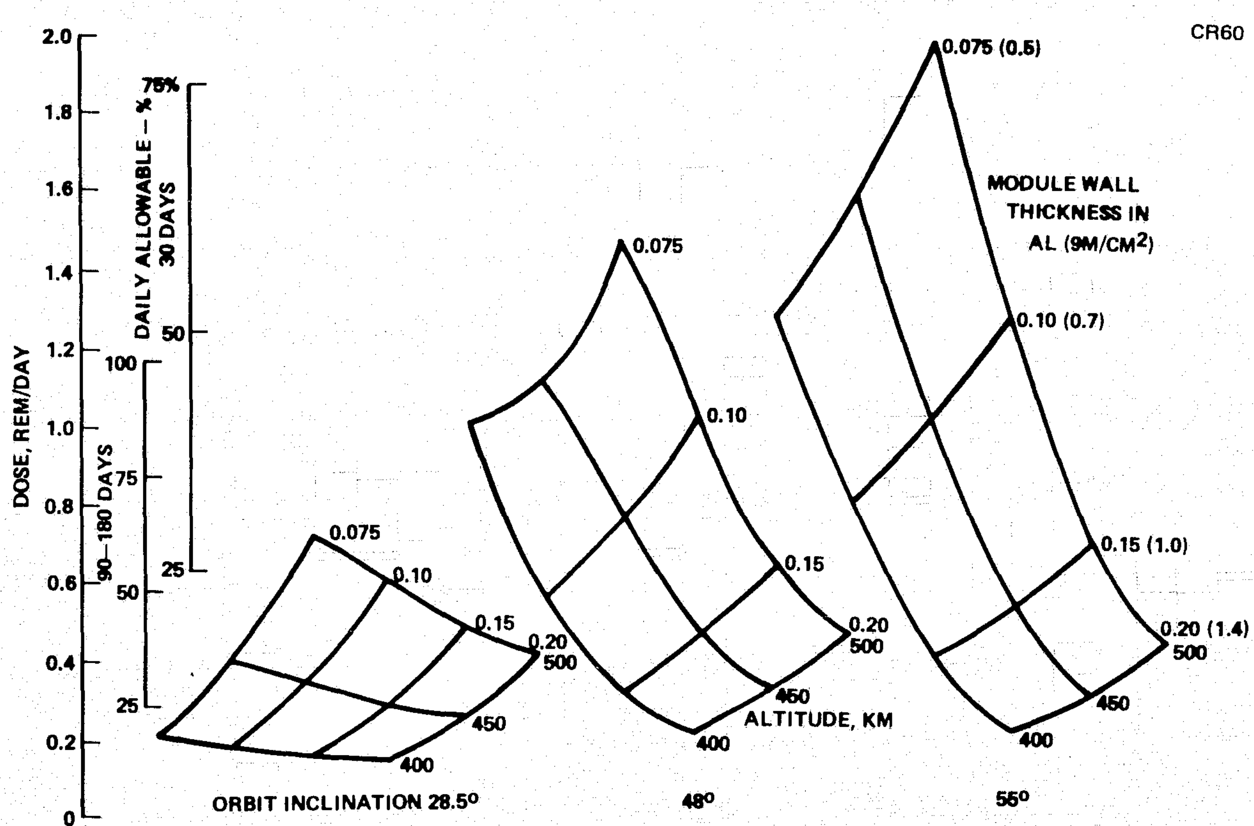


Figure 6-15. Module Skin Dose

560 km, the dose received would be equal to the allowable for a 90 to 180 day mission. At 55 degrees, the dose is increased and additional shield (beyond 0.1 in.) is required just for trapped radiation. In addition, the solar cosmic ray dose (November 12, 1960 model flare) must be accounted for. The biowell thickness/flare dose received relationship calculated is:

Thickness (gm/cm^2)	Skin Dose (REM)
2	88
4	36
6	18

Thus, at 55 degrees a portion of the allowable dose must be allocated to the potential of encountering a solar cosmic ray event.

The dose received during EVA activity is primarily governed by passages through the South Atlantic anomaly (a low dip in the Van Allen Belt because of the tilt and displacement of the earths magnetic field) and the horns (the collapse of the field near the polar region). As EVA durations are increased scheduling between these high intensity radiation regions becomes more difficult. The EVA dose was calculated by integrating the dose received assuming the crewmen were inside the SCB during these passages.

The results are shown in Figure 6-16 for various inclination, altitude, daily EVA shift durations, and EVA suit thicknesses. As seen for the 28.5 degree orbits, the EVA dose received is less than 50 percent of the allowable, even for very long shift durations (15 to 19 hours per day). Thus EVA, with a Shuttle EVA suit (0.1 gm/cm^2 thickness) can be accomplished as needed for 28.5 degree missions.

For higher inclinations, i.e., 55 degrees, both a thicker suit and short EVA duration must be used. Careful scheduling has shown that at 55 degrees the Shuttle EVA suit can provide adequate protection for most of the EVA schedules required. In addition, a 6-hour shift duration was found to maximize the EVA man-hours attainable for reasonable EVA dose allocations.

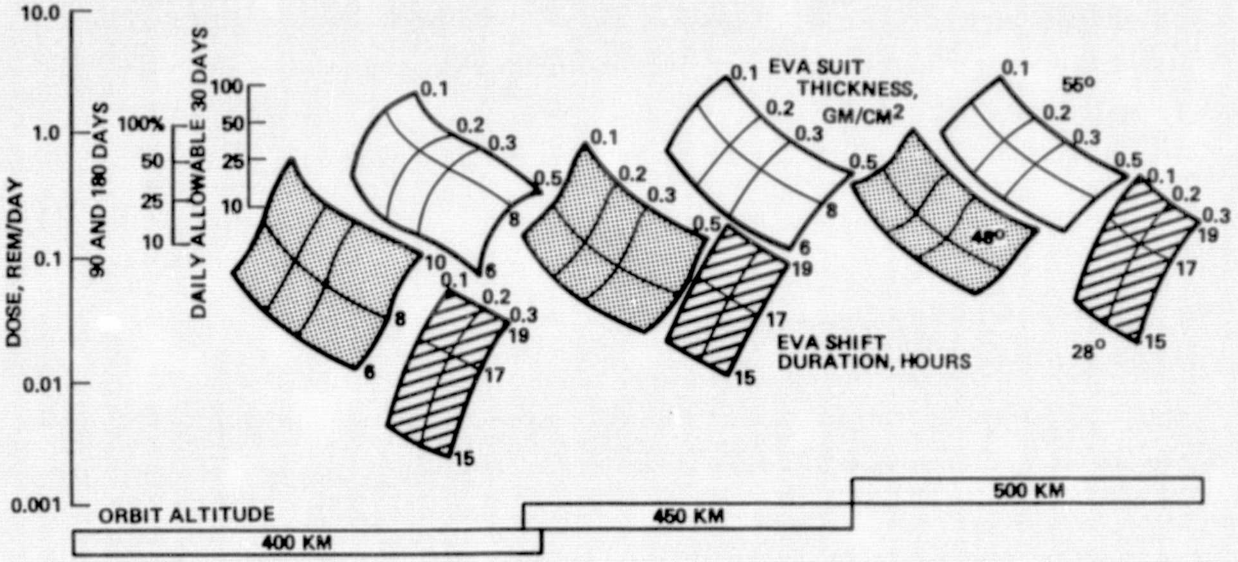


Figure 6-16. EVA Daily Skin Dose

6.1.4.3 Shield Calculations

The inherent module shielding and the Shuttle EVA suit were found adequate for all planned activities on a 28.5 degree inclination mission. For 55 degree missions, additional module and biowell shield addition requirements were calculated to minimize the overall module weight addition, as shown in Figure 6-17. This minimum solution was then found as a function of EVA dose allocation (see Figure 6-18). It thus appears that for a 55 degree orbit at 450 km, the EVA allocations should be about 100 REM for a 6-month mission. The minimum module/biowell shield combination would then be 0.060 in. added to the module and a 0.43-in.-thick biowell for a total 1500 kg shield penalty.

6.1.4.4 Radiation Analysis Conclusions

The conclusions reached from the radiation analysis were:

28.5 degree Mission

- Nominal module design 0.1-in. Wall) is adequate to 560 km.
- Two EVA shifts per day can be scheduled around anomaly passage.
- Shuttle suit is adequate for planned durations.

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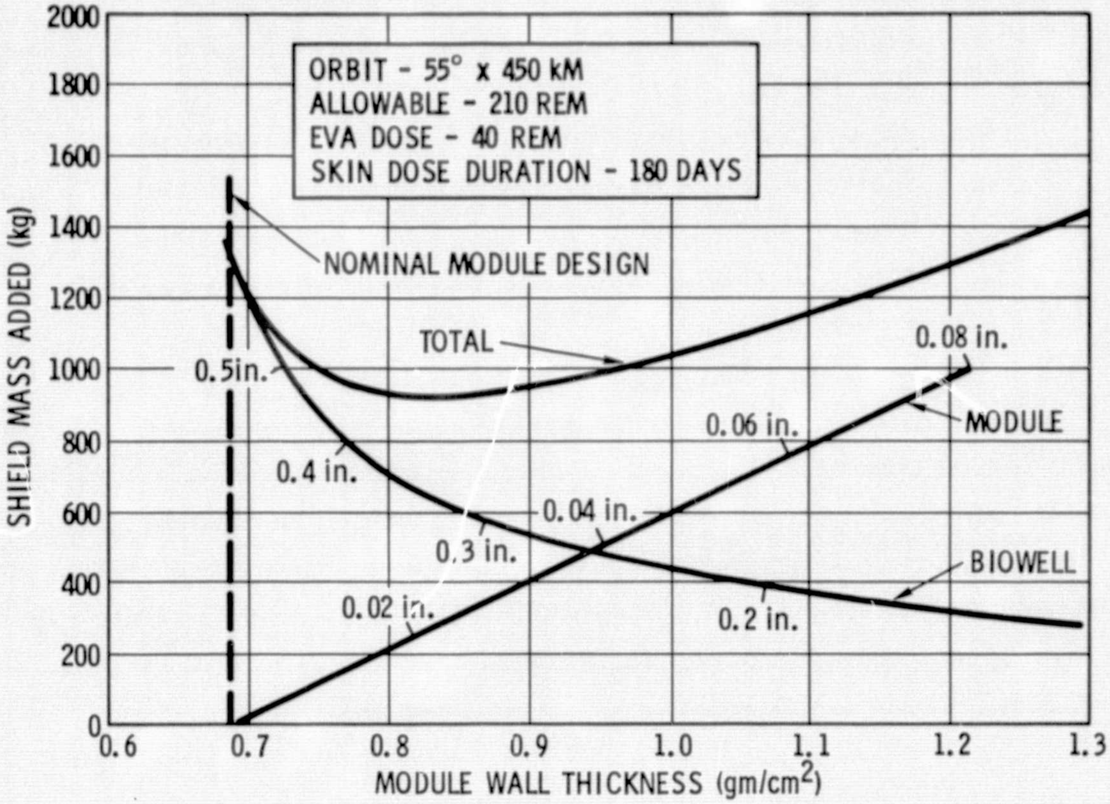

Figure 6-17. Module/Biowell Shield Optimization

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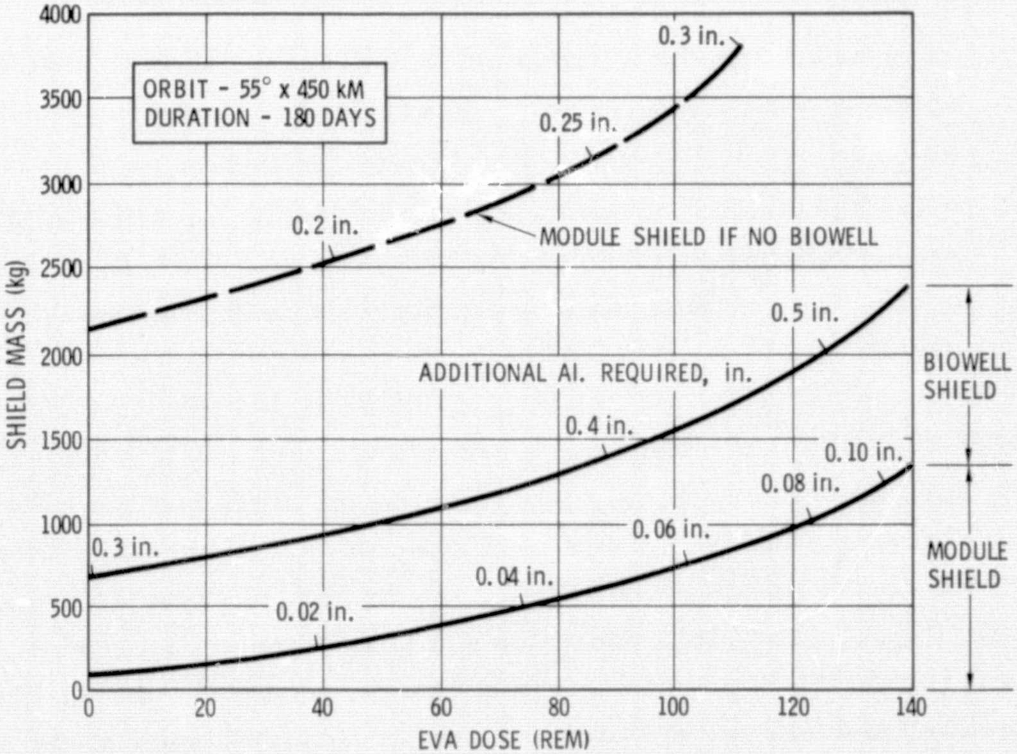

Figure 6-18. Minimized Module/Biowell Shield Required

55 degree Mission

- Additional module shielding is required (approx. 0.06-in. Al, 800 kg)
- Biowell is required (approx. 0.4-in. Al, 700 kg)
- Shuttle suit provides marginal protection; additional protection is desired.
- A single 6-hour shift per day maximizes achievable EVA man-hours.

6.2 SPACE PROCESSING OPERATIONS

The eventual commercialization of space processing operations will result from a vigorous basic research program in materials science and technology. A spaceflight demonstration program will have to reduce the risks and uncertainties of space processing operations to the point where private capital funding of production process optimization and pilot plant operations would lead to full-scale commercial production in space.

In order to accommodate a wide range of product demonstration operations, a Space Processing Development Facility (SPDF) was defined. The operational requirements of SPDF are as follows:

A. Support advanced materials science research and applications by offering a capability (electric power, volume for equipment, run time, on-orbit duration, etc.) beyond Spacelab.

B. Allow the conduct of engineering development tests to: establish production techniques, develop processing equipment, demonstrate economic advantages of low-gravity materials processing, and develop process optimization data.

The SPDF will form the design basis for future commercial modules dedicated to specific unique products (enzymes, laser glass, silicon chips, etc.). It was determined that the SPDF should have an operating compartment for activities associated with processing, process control, specimen analysis, specimen storage, sample preparation and environmental isolation. Capabilities for on-orbit storage in a dormant mode, on-orbit maintenance, modification, and equipment changeout also is required, with equipment rack-mounted (Spacelab type racks) or aisle-mounted.

The SPDF must provide work space for a crew of two persons during its operational missions which will extend from 30 to 90 days before crew changes and/or equipment changes occur. The specific tasks will vary as the procedures change from, say, biological processing to crystal growing. For many functions, one crewman per shift will be adequate to operate the SPDF. However, some procedural steps may require up to two crewmen.

The typical process run can be days (say 40 to 50 for bioprocessing) or hours (say 15 to 25 for processing of certain glass materials). Figure 6-19 shows an example of the process steps in a run. During critical parts of the process run, the SCB will have to maintain "g" levels of approximately 10^{-3}* (some excursions to $10^{-2} \rightarrow 10^{-1}$ may be permissible a small percentage of time). Examples of critical parts of a process run would be preform shaping in a glass production and culture growth in bioprocessing.

Because this is a multipurpose facility, generally more than one run or test or demonstration in a biological or nonbiological discipline will be occurring at the same time. This requires that integrated planning and timelining for

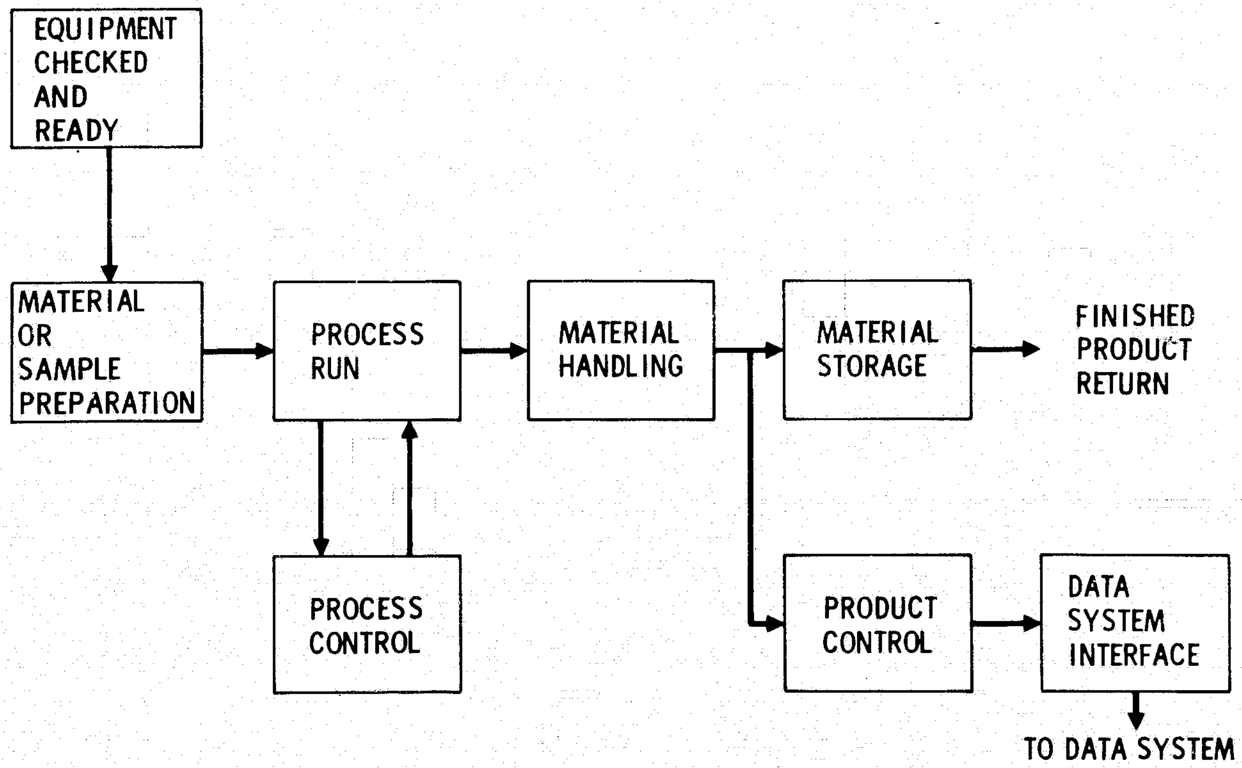

Figure 6-19. Steps of a Typical Process Development Run

*Analyses revealed that the SCB is capable of satisfying this requirement for the general spectrum of operations considered in the study.

both crew and equipment use will be necessary. In addition to its operation as a Space Processing Development Lab, the SPDF could, with equipment changes, be used for:

- Life sciences work
- Contamination measurements facility
- Laboratory for conducting exposure experiments
- Testing, Standards and Calibration Laboratory for space construction.

6.3 SATELLITE POWER SYSTEM TEST OPERATIONS

The SPS test operations on TA-1 and TA-2 consist of controlling and operating the: (1) beam mapping satellites (a small one for field strength and RFI measurements and a large one with a 360m span for mapping the main lobe), (2) test antennas, and (3) high-voltage solar collector.

6.3.1 Operation of Beam Mapping Satellites

Beam mapping satellites (BMS's) are controlled from the space station, but are deployed and serviced from the Orbiter. This mode allows continuous operations and eliminates the complexity (and possible hazards) of remote-controlling these vehicles to rendezvous with the station for servicing. As proposed, the beam mapping satellite can be immobilized while the Orbiter performs the terminal rendezvous maneuver.

Continuous tracking of the beam mapping satellites from the station by ladar allows both accurate command of BMS orientation with respect to the station and precise pointing of the test antennas. For precise pointing, the ladar is mounted on the test antennas for a direct measurement of the angle between line of sight (to the beam mapping satellite) and the geometric centerline of the antenna. From this data, the station computer predicts the future position of the beam mapping satellite and the propulsive commands necessary for specific maneuvers. The small beam-mapping satellite is placed in a slightly elliptical orbit with a slightly different inclination, but with the same period and average altitude of the space station orbit. As a result, the BMS executes circling maneuvers about the station for RFI measurements. Since the future position of such trajectories is accurately predicted (given accurate tracking of a segment), ladar coverage need not be hemispherical.

Crew functions during this operation consist of monitoring the BMS via telemetry and tracking readouts and initiating operational commands to the satellite. Servicing of the BMS can be accomplished in conjunction with other logistics missions since BMS expendables are on the order of a ton per year.

6.3.2 Operation of Test Antennas

Operation of the antenna includes manual control of its pointing (using a tracking readout from the ladar) as well as monitoring performance during each test, initiating on/off commands, etc. To avoid interaction of the stations' automatic control system with this manual pointing function, the station RCS system is turned off during the test period. This is feasible since the station normally flies in a stable zero-gravity gradient mode.

Considerable EVA is also required during antenna tests to alter configurations. Several foams of intentional mechanical misalignments are introduced (both TA-1 and TA-2); electronic circuits are exchanged (TA-1 and TA-2); and the center high-power density subarray is interchanged with one giving uniform power across the TA-2 antenna. As is typical in any test program, considerable allowance must also be made for EVA to effect repairs and maintenance of the equipment.

6.3.3 Tests of High-Voltage Solar Collectors

Prior to the use of a high-voltage solar collector in tests of SPS antennas, its performance (both electrical and structural) is checked under a variety of conditions.

Structural tests include measurement of basic bending frequencies. Hence, the station RCS system is used to excite a bending mode and then turned off to observe internal damping characteristics. Structural response to thermal transients when passing from light to dark is also measured for a number of orientations with respect to the sun. In both the cases, integral strain/displacement instrumentation is utilized (after an initial EVA optical/photographic survey of the collector's geometry).

Plasma leakage is measured by determining voltage/load curves for the array when both parallel and perpendicular to the local velocity vector. Large calibrated resistors that thermally dissipated the electrical energy are used during these tests. Voltage load curves are also established for various inclinations to the sun.

6.4 ALTERNATE CONSTRUCTION SYSTEM

The alternative to the fixed work station construction system is one which allows the work station to be moved about the part. A construction platform was conceived (see Figure 6-20) to be used in comparing this approach to the fixed work station developed in the study. The construction platform concept is made up of 14 beams that are 17m long, 4m wide and 3 to 4m deep. These beams can be delivered in a single Shuttle launch, deployed and assembled to form a 28m by 34m platform. In order to provide a "universal) work/EVA translation surface, 14 isogrid "floor" panels are installed at the end. A three segment boom having a Shuttle derivative arm also is included. With this boom and RMS, "reach-around" access is provided over the entire

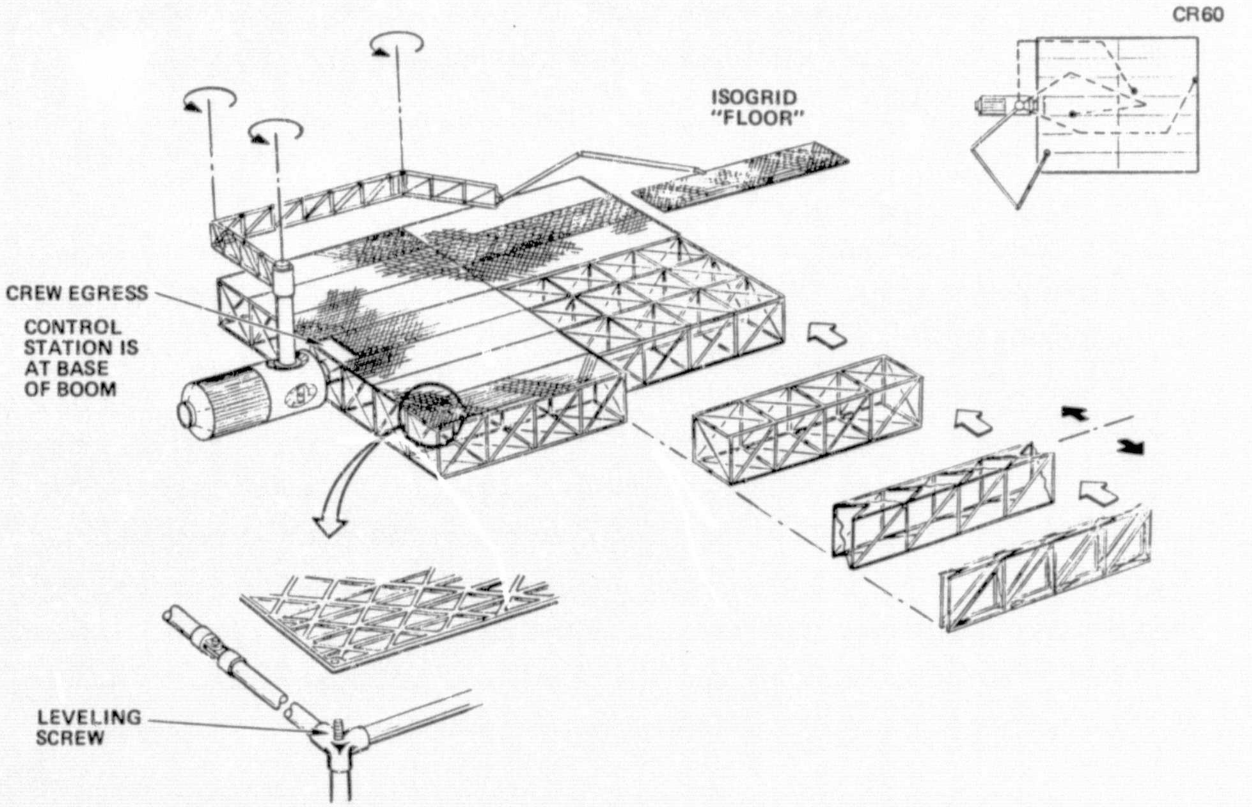

Figure 6-20. Construction Platform Concept

work surface. The boom segments are made from fairly deep beams to give good vertical stiffness; lateral motions are controlled by a rate feedback system.

The fabrication of the power platform was considered using the construction platform (see Figure 6-21). The fabrication is done in roughly 32m segments as opposed to the continuous fabrication resulting from use of the fixed work station concept. Each 32m segment is made up by first fabricating four 32m beams and placing them in prelocated (using surveying techniques) guides. The 28m end beams are fabricated and attached at either end. For the first segment, the solar array rolls are attached to the end beam and electrical connections made by EVA along buses located on the 32m beams. Upon completion of the segment, it is pushed outboard and the next segment constructed

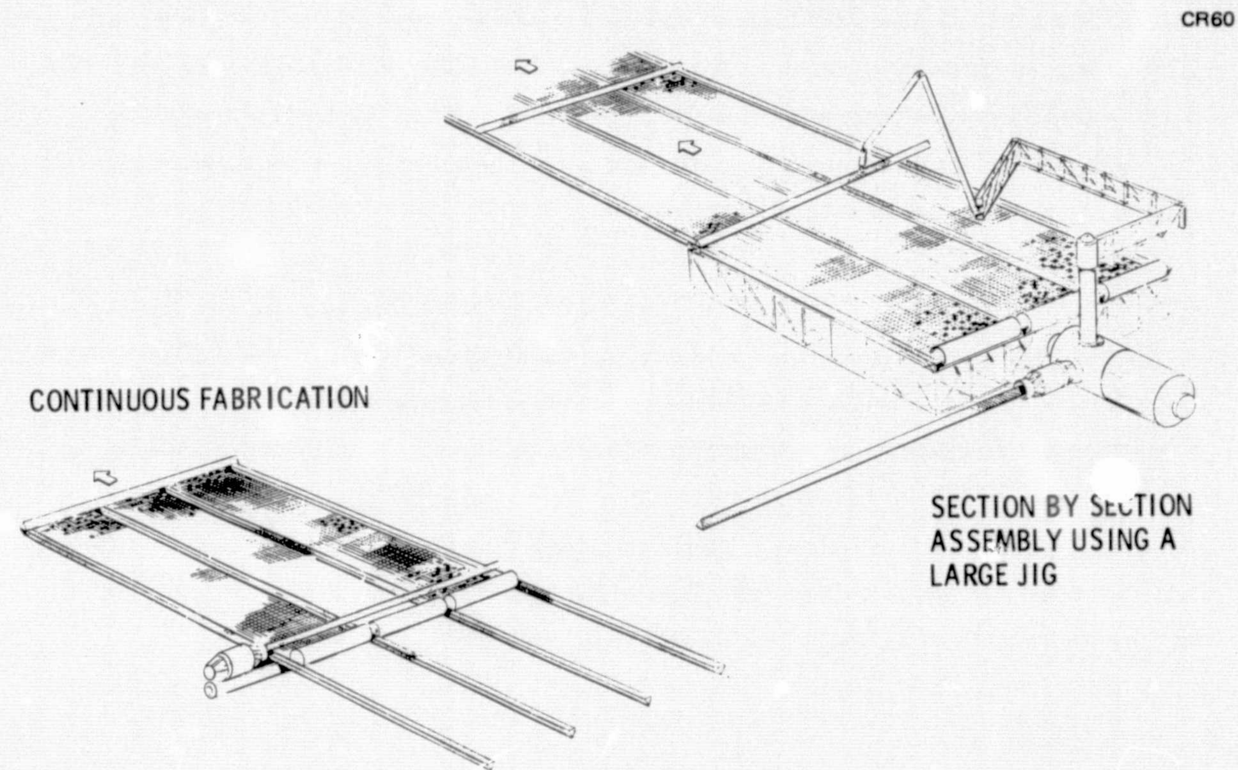

Figure 6-21. Alternative Fabrication and Assembly Systems for 456 KW Power Platform

in a similar manner. This process repeats until the entire power platform is completed. Special fittings are then installed which can position the array while a gimbal is installed. The array is then attached to the gimbal to complete the system. This approach takes about 50 percent longer than the continuous fabrication approach does. The extended time results from the fact that extensive EVA is required and there are more tasks involved due to the piecemeal assembly approach.

The use of the construction platform to assemble a 100m radiometer also was evaluated (see Figure 6-22). The analysis revealed that the construction platform required significant modification from the 28 by 34m configuration shown in Figure 6-20. The boom system must be increased so that it can provide a 50m vertical and 100m horizontal reach, and the platform has to be increased to over 50 by 100m in size. A cheaper alternative (which was selected) is to install a standoff having a turntable on the end of the 28 by 34m platform.

There is little difference between the two systems for assembling the 100m radiometer since the addition of the standoff and turntable to the construction platform, in essence, converted it to the fixed work station concept. The time was longer because of the EVA penalty. This was offset somewhat by the fact that the construction platform provides for off-line assembly, which allows some efficiency in construction.

The systems derived in the study for each approach were next compared in terms of what it takes to place them on orbit (see Table 6-6). The overall conclusion of the analysis is that the fixed work station approach is superior, particularly for large structures. The fixed work station can be delivered and assembled on-orbit very quickly. The construction platform, being heavier and more complex, requires more Shuttle delivery flights, is significantly more expensive, and has a higher program risk because of the number of parts that must be assembled on orbit.

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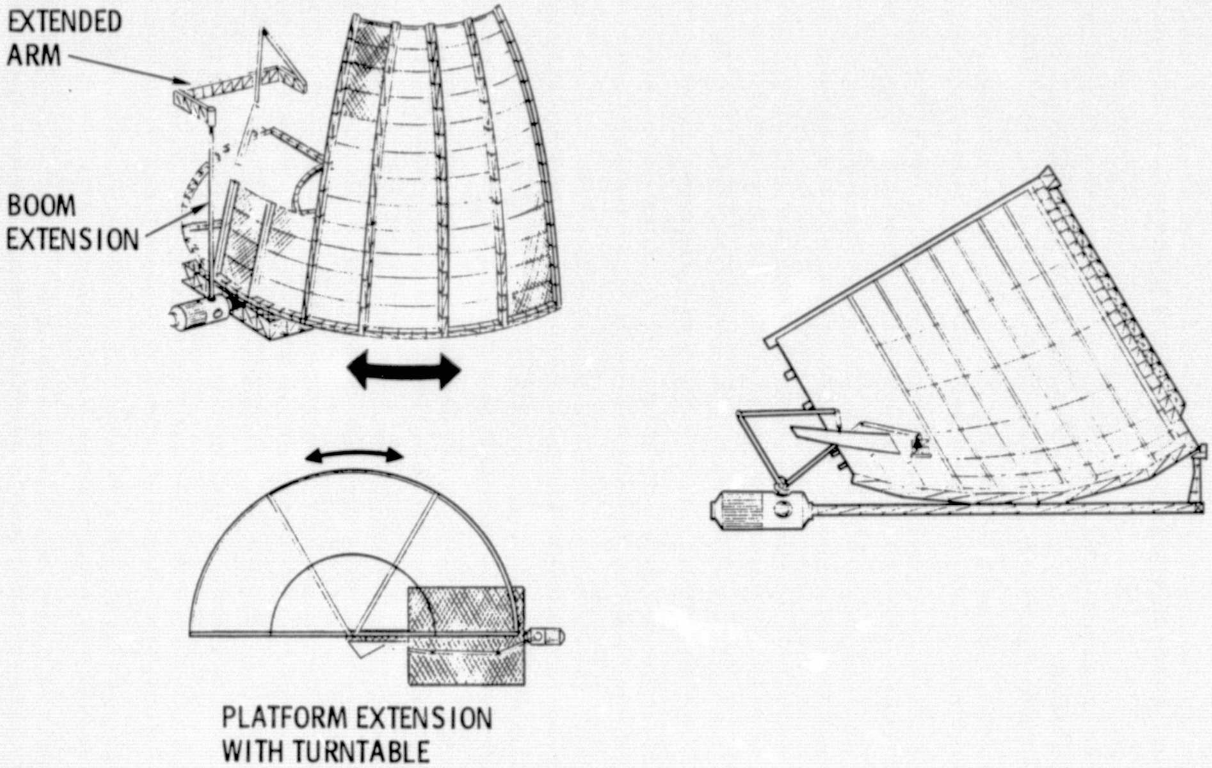

Figure 6-22. Alternate Assembly Systems for 100M Radiometer

Table 6-6

CONSTRUCTION SYSTEM COMPARISON OF SYSTEM DELIVERY AND SETUP

Comparison Consideration	Fixed Work Station	Deployable Platform
Number of Systems	5	4
• Platform/Standoff	(1)	(1)
• Cranes	(1)	(1)
• Boom System	(-)	(1)
• Cherry Picker	(1)	(-)
• Control Station	(1)	(1)
• Turntable	(1)	(-)
Weight	7,000 kg	12,000 - 20,000 kg
Number of Parts Assembled on Orbit	6	34
Time to Assemble (Work Shifts)	3	46
Shuttle Delivery Flights	1	3
Utility Provisions	2	54
• Light Banks		
• Utility Outlets		
Cost — Hardware and Transportation Only	$180 Million	$250 - 370 Million

Section 7
PROGRAMMATICS

This section presents summary level cost and schedule information for the system concepts that were developed in Part 3. More detailed cost and schedule data may be found in Volume 5 of this report.

The ground rules and assumptions used in the programmatic activities are as follows:

1. Cost estimates are reported in constant mid-fiscal year (April) 1977 dollars.
2. When required, previous-year dollars are escalated by using DoD price escalation factors and DCA price level indices.
3. Funding distributions are in October 1 through September 30 fiscal years.
4. Cost estimates are commensurate with program definition at the time of the estimate, the relative level of study effort, and with the understanding that the estimates are only for prelimianry planning and tradeoff study purposes.
5. Cost estimates exclude NASA institutional costs, such as base support contractor personnel costs, civil service personnel salaries and allowances, and administrative support technical services.
6. NASA furnished Shuttle costs of $19.1 million per flight in mid-fiscal year 1977 dollars are used. This cost is assumed to include use of the docking/airlock module and the Orbiter RCS, power, and ECLS kits required by the shuttle tended operations.
7. The emphasis is on relative costs rather than on absolute costs.
8. The cost estimates are developed and documented in consonance with the latest JSC approved Work Breakdown Structure (WBS) and WBS dictionary.
9. The cost estimates assume no dedicated flight test hardware.

10. All flight crew and training costs not included in the per flight Shuttle costs are excluded from the total program costs.
11. It is assumed for funding purposes that the first available funding will begin at the start of fiscal year 1979.
12. It is assumed for scheduling purposes that the first Space Station Launch will be January 1, 1984.
13. Costs for this study are derived using the following criteria as a base:
    - Building block costs derived from the JSC Modular Space Station Phase B Study.
    - Cost Estimating Relationships (CERs), cost factors, and best judement estimates obtained in consonance with knowledge engineering personnel are used in obtaining the remaining costs.
14. Learning curves are not used in calculating multiple usage because this can introduce an artifical cost differential for accomplishing the same objectives on different options solely because of an arbitrarily assigned position or difference in sequence on the curve.
15. The CERs that are used are formulated from historical data stored in the MDAC data bank.
16. The cost of GFE equipment is not included in the estimate but the cost, if any, of modifying GFE to meet the requirements of this program is included.
17. It is assumed that the SCM, CS and SPDF are designed in that order. This permits a substantial amount of cost avoidance. DDT&E costs for portions of the CS and SPDF that are similar to the SCM may take advantage of the previous SCM design, and therefore be substantially reduced.
18. ATP was assumed to be 1 October 1979 with the first launch at start of December 1983. This 50-month development program is considered of nominal length based on a combination of controlled funding buildup with utilization of existing hardware and experience on previous programs and is therefore somewhat shorter than prior major programs.
19. The station buildup schedule was based on a launch every 30-days. The activity during Shuttle-Tended phase also required a launch

every 30 days. Once the station is continuously manned the required launches are reduced.

20. First priority was given to Construction of Space Power mission items.

21. Construction activity was based on constructing one objective element at a time. Optimizing the use of the Space Construction Module builds the objective elements in series with the initialization of testing of one objective element while the next one is being fabricated.

22. Best usage of EVA time resulted in a two 10-hour shift operation including 6 hours per shift of actual EVA time.

23. The detailed schedule was only carried through fiscal year 1988 but the program has the capability and flexibility for continuing development and operations beyond that time.

7.1 EVOLUTIONARY PROGRAM

An evolutionary program with increasing capability has been developed as the baseline for this study as shown schematically in Figure 7-1. This program

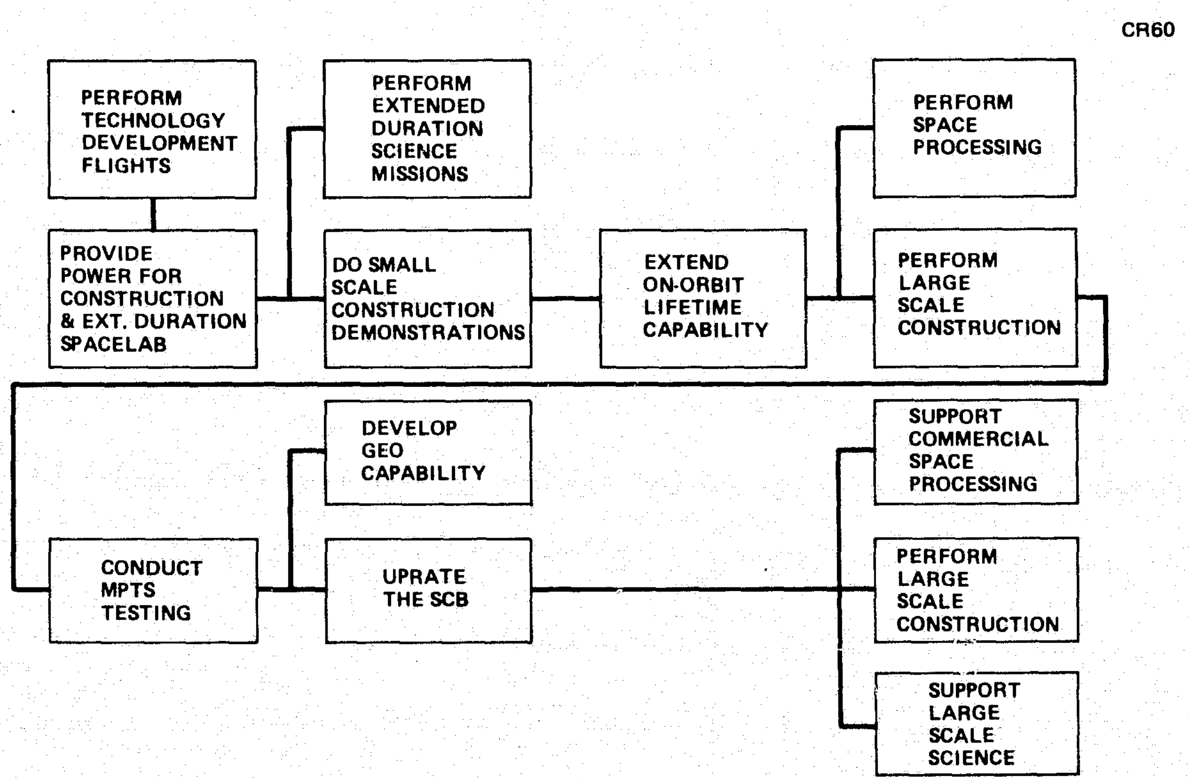

Figure 7-1. Evolutionary Program Baseline

starts with technology development activities which use only the Shuttle and Spacelab. As additional resources become available, more extensive orbital activities are possible, including construction demonstrations, space processing and extended duration science missions. At this point, it appears logical that orbital stay-time requirements will have to be increased significantly and additional orbital capability will be required to permit large-scale construction and testing in support of SPS and earth service antennas, and long-duration space processing activities. Eventually, a further uprating of the orbital Space Construction Base will be required to support very large-scale activities such as commercial space processing plants, prototype size SPS pilot plant construction, multimodule science activities, and geosynchronous and oribtal depot operations.

A logical evolution of space capability incorporates an orderly transition from the Shuttle/Spacelab systems using only STS hardware elements, to Shuttle-tended operations with some elements being left permanently in orbit, to a continuous operations phase with on-orbit habitability. The entire concept is designed to facilitate modular growth to ultimately accommodate a large crew complement. This concept is shown in Figure 7-2 including the major activities that are conducted in each phase.

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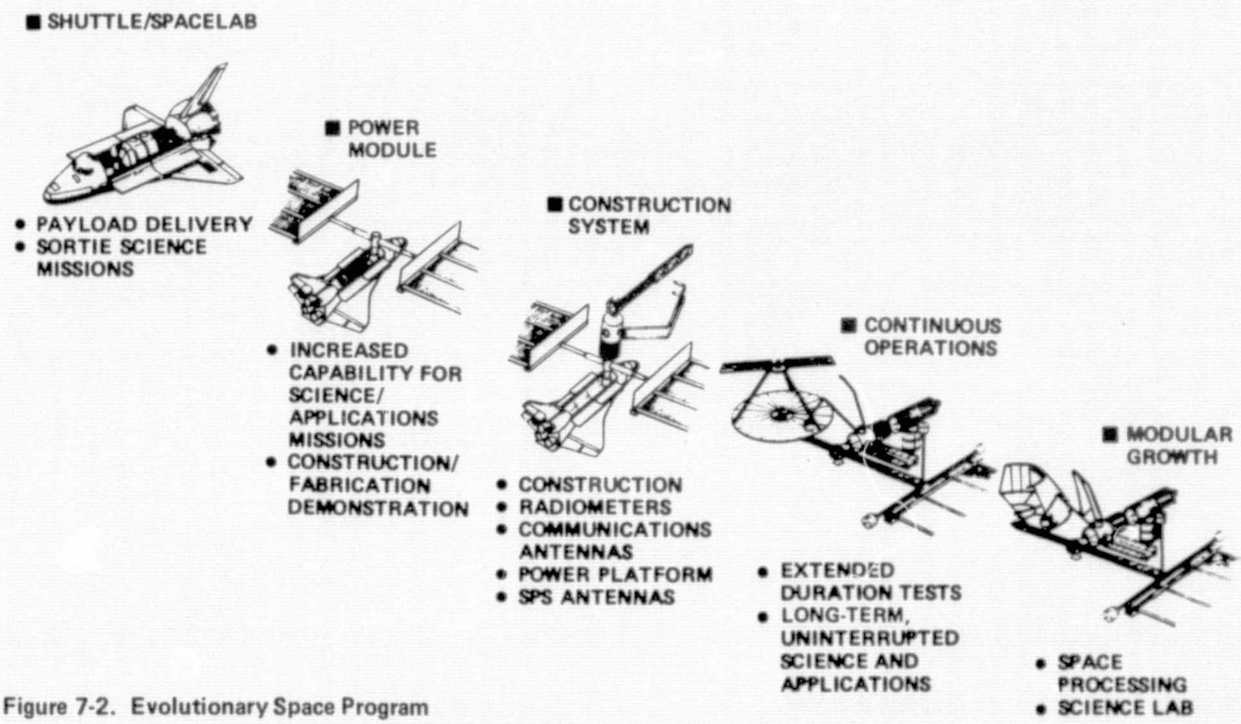

Figure 7-2. Evolutionary Space Program

7.2 PROGRAM SCHEDULE

Figure 7-3 shows the schedule for the principal activities of the baseline program from the start of DDT&E through the completion of each activity. The triangle symbols indicate the operational date for the hardware that is required to support each activity. For example, the SPS Test Article 1 (TA-1) activity requires a Low Earth Orbit antenna (LEO), two Beam Mapping Satellites (BMS), and a Geosynchronous free-flying antenna (GEO).

The Technology Development phase is considered to be a precursor activity to the SCB and therefore the cost for this was not included in the program cost. The Space Lab (SL) element that is used in the Space Processing and Science activity was assumed to be GFE since it is basically the same hardware that is already under development.

The Shuttle is used for all orbital activities up to early 1984 when the Construction Shack is placed in orbit. The Construction Shack was launched at this time because analysis indicated that early continuous manning cap-

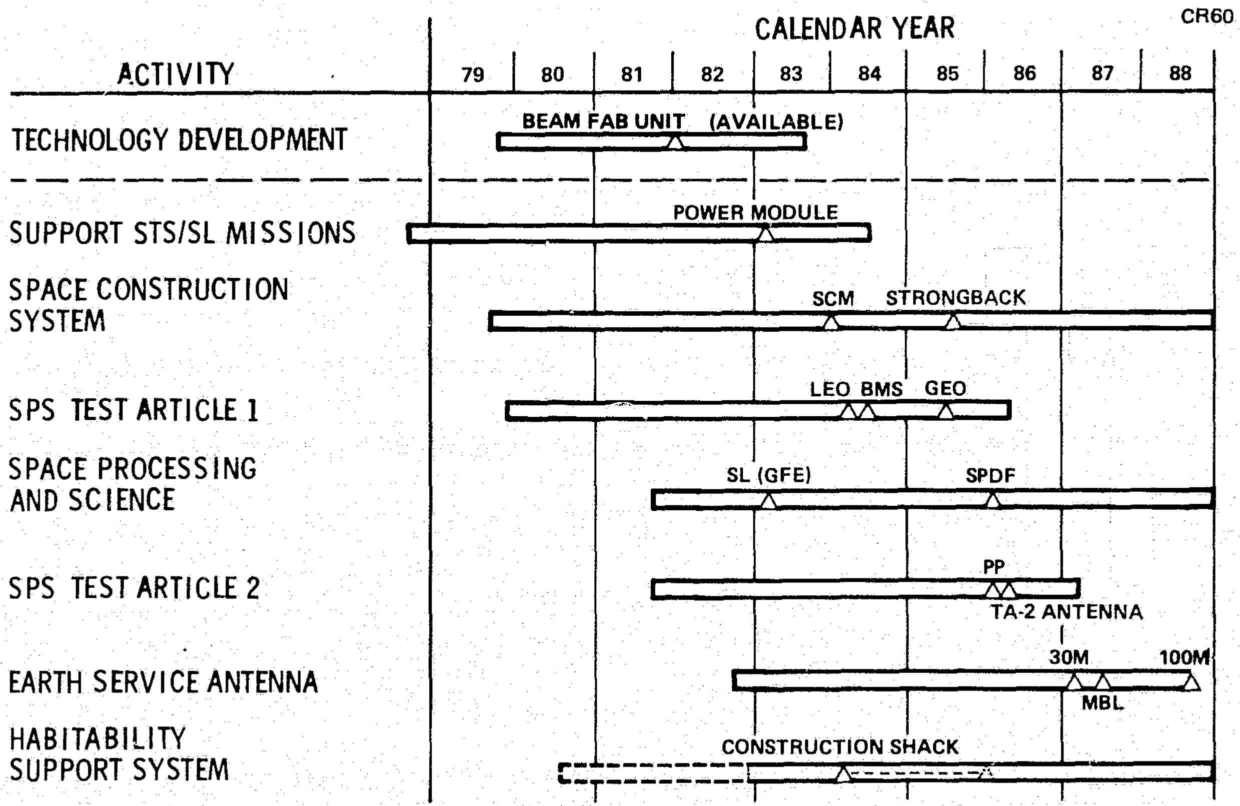

Figure 7-3. Baseline Program Schedule

ability would significantly lower the total program cost compared to a Shuttle-tended mode of operation. If annual funding during the DDT&E period must be reduced, this can be accomplished by delaying the launch of the Construction Shack as indicated by the phantom triangle, but total program cost will be greater.

Assuming a 30-day Shuttle capability, the on-orbit requirements for various construction items were assessed relative to the Shuttle's capability (Figure 7-4). As an example, it was found that several items are not compatible with a single sortie mode because more than one Shuttle flight is needed to deliver hardware. Others were doubtful due to such things as RMS reach capabilities and orbit stay time. This investigation revealed that of the mission hardware items considered, only the power platform and TA-1 appear to be compatible with such a single Shuttle sortie mode of operation. Multiple sorties can accommodate additional mission hardware items while a Shuttle-tended space construction module can support all of the construction tasks.

7.3 SPACE CONSTRUCTION BASE HARDWARE COST

This section provides the estimated cost for each element of hardware of the Space Construction Base. Included in these costs are the DDT&E and Production necessary to deliver the end items. Transport to orbit and operations cost are not included (see Paragraph 7.5).

CONSTRUCTION ITEM	PAYLOAD WEIGHT/ VOLUME	TIME	POWER	MANIP-ULATOR	EQUIP/ MENT TOOL INSTALL-ATION	COMPATIBLE MODES		
						SINGLE SORTIE	MULTI-PLE SORTIE	SHUTTLE TENDED SCM
TA-1 DEPLOY/ASSEMBLY						✓	✓	✓
TA-1 FABRICATION AUTO ASSEMBLY								✓
TA-2 DEPLOY/ASSEMBLY							✓	✓
TA-2 FABRICATION AUTO ASSEMBLY								✓
MBL ASSEMBLY								✓
30M RADIOMETER ASSEMBLY								✓
100M RADIOMETER ASSEMBLY								✓
POWER PLATFORM DEPLOY							✓	✓
POWER PLATFORM ASSEMBLY						✓	✓	✓
POWER PLATFORM FABRICATION						✓	✓	✓
POWER PLATFORM FAB-RICATION AUTO ASSEMBLY								✓

*ASSUMES 30-DAY SHUTTLE

GENERALLY COMPATIBLE MARGINAL GENERALLY NOT COMPATIBLE

Figure 7-4. Sortie Mode/Construction Requirements Compatibility *

7.3.1 Power Module Cost

The costs shown by subsystem in Figure 7-5 reflect the estimate end item cost of a 30-kW power module with free-flying capability which can support the Shuttle sortie missions early in the program and later can be attached to the Space Construction Base to provide power for base operations. Included in these costs are the DDT&E and Production for both subsystem and system levels necessary to deliver the end item. The end item system level costs (integration) have been allocated to the subsystem categories.

The cost estimates are based on current state-of-the-art technology including utilization of the SEPS-type solar array reflecting a cost effective design approach.

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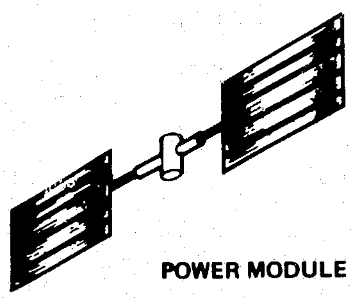

SOLAR ARRAY	$76M
RADIATOR & ELECTRICAL	24
ATTITUDE CONTROL	28
STRUCTURE	22
TELEMETRY & RCS	20
MISC	4
	$174M

Figure 7-5. Power Module Costs

7.3.2 Construction System Cost

The construction system is comprised of four elements as shown in Figure 7-6. The cost estimates for the module reflect utilization of Shuttle orbiter components particularly in the ECLS and Information Subsystem resulting in significant DDT&E cost avoidance.

The cost estimates for the crane are based on a design approach using the orbiter RMS design technology with increased size and improved capability.

The cost of the Cherry-Picker, which operates as part of the crane control system, and the strongback constructio n fixture, when added, resulted in the total construction system cost.

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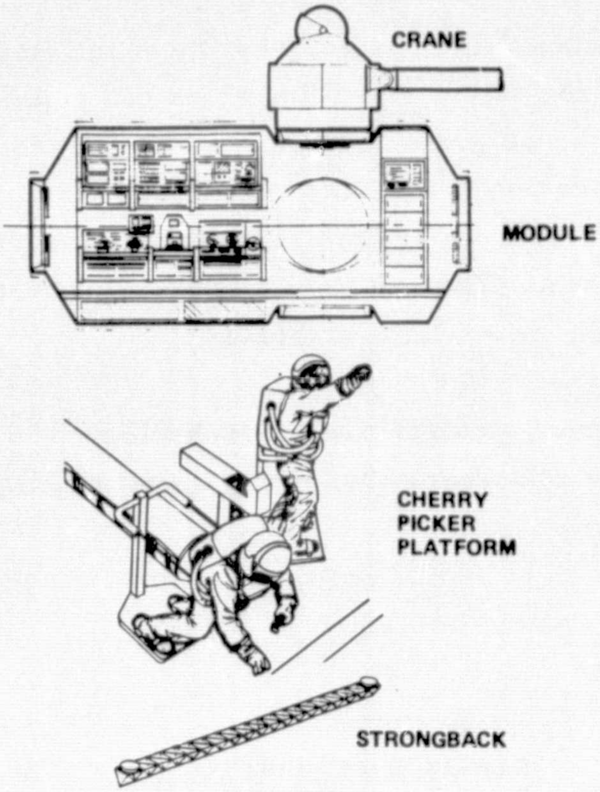

MODULE	\$128M
CRANE	122
CHERRYPICKER	15
STRONGBACK	22
	\$287M

Figure 7-6. Construction System Cost

7.3.3 Habitability Support System (Construction Shack)

The costs shown in Figure 7-7 by subsystem indicate the estimated cost of the Construction Shack element of the Space Construction Base. The Construction Shack is a habitability module equipped to support a 7-man crew for continuous space operation. Included in these costs are the DDT&E and Production necessary to deliver the end item module. The end item system level integration costs have been allocated to the subsystem categories.

The cost estimates reflect use of orbiter subsystem components, particularly in the ECLS, Information, and Guidance and Navigation subsystems, as well as the airlock. This results in a significant DDT&E cost avoidance to the Construction Shack. Figure 7-8 indicates by subsystem the use of orbiter equipment.

7.4 MISSION HARDWARE COST

This section gives the cost estimates for the mission hardware included in the base program. The estimates include DDT&E, and Production costs to deliver the end items. Transportation and operations costs are not included (see Paragraph 7.5).

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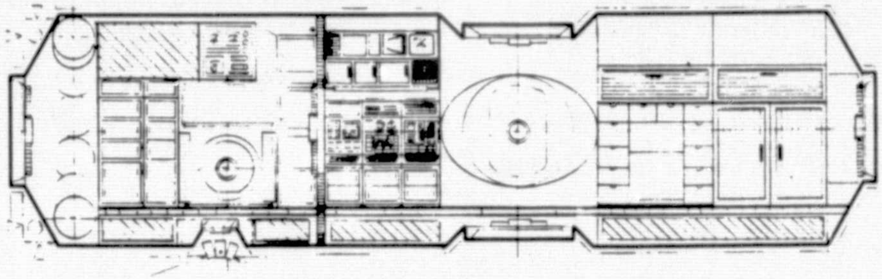

STRUCTURE/MECH	$36M
ECLS	75
ELECTRICAL	2
INFORMATION	78
CREW SUPPORT	11
GUIDANCE & NAV	38
	$240M

Figure 7-7. Habitability Support System Module Cost (Construction Shack)

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SUBSYSTEM	% APPLICABLE	TYPICAL
• ECLSS	40-50	• PRESSURE CONTROL, TANKS, HEAT EXCHANGERS AND VALVES
• ELECTRICAL POWER	5-10	• INVERTERS, SWITCHES AND CIRCUIT BREAKERS
• CREW HABITABILITY	65-75	• EVA EQUIP, FOOD STORAGE AND PREPARATION, AND CLOTHING
• PROPULSION - RCS	70-80	• FUEL AND OXIDIZER TANKS, THRUSTERS, VALVES, AND PRESSURIZATION SYSTEM
• GUIDANCE AND CONTROL	40-50	• RCS DRIVER ELECTRONICS, HAND CONTROLLERS AND CONTROLS/DISPLAYS
• DATA MANAGEMENT AND COMMUNICATION	75-80	• COMPUTER, MDM'S, ANTENNA, RECEIVERS, TV CAMERAS, AND SIGNAL CONDITIONERS
• RMS	50	• TECHNOLOGY

Figure 7-8. Orbiter Hardware Summary for Space Construction Base Applications

7.4.1 Power Platform

The costs to development and produce the power platform are indicated on Figure 7-9. This device, although about three times the size of the power module, costs less because it does not have the support system capability that is required for the power module.

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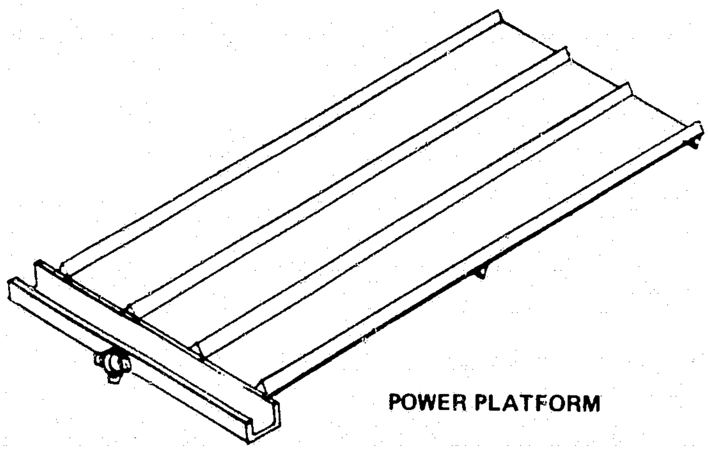

SOLAR ARRAY	$94M
BATTERIES	5
ASSEMBLY FIXTURE	29
STRUCTURE	12
RCS PODS	27
TOTAL	$167M

Figure 7-9. Power Platform

7.4.2 SPS Test Articles

Figure 7-10 presents the cost estimates for development and production of the SPS TA-1 and TA-2 antennas. TA-1 antenna operates in two different configurations, in LEO while attached to the SCB and at GEO as a free-flying satellite. The LEO antenna is relatively simple consisting of structure and MPTS electronics, while there is considerable additional hardware that must be added to permit operation at GEO as an independent satellite.

The complete TA-2 device consists of the 15 panel MPTS antenna and the power platform to supply power for the testing. The batteries required to achieve the high peak power loads required for these tests are included in the cost estimates shown for the TA-2 antenna.

The beam mapping satellites listed under Support Systems are used for both TA-1 and TA-2 testing, and also for testing and checkout of the Radiometers and Multi-beam Lens Antenna. The beam mapping satellites used the NASA Multimission Modular Spacecraft (MMS) as building blocks, which reduced their cost significantly.

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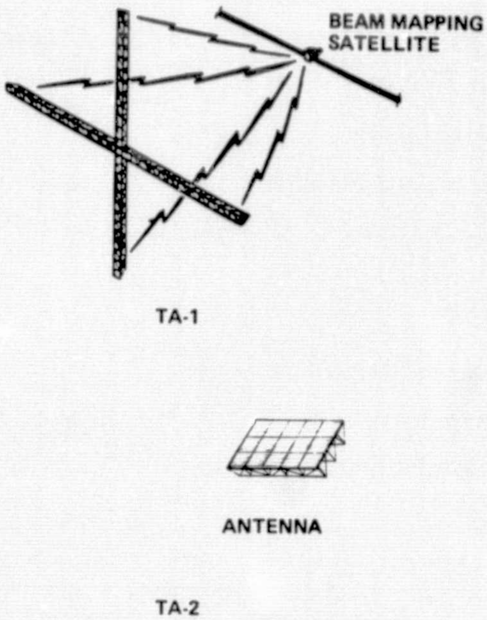

TA-1 ANTENNA		$288M
LEO ANTENNA		63M
GEO HARDWARE		225M
G&C	102	
POWER	98	
RCS, TTC	25	
SUPPORT SYSTEMS		
SMALL BMS		$18M
360M BMS		94M
TA-2 ANTENNA		($133M)
STRUCTURE		48M
ELECTRONICS		23
ASSEMBLY TOOL		28
BATTERIES		14
RCS		7
PALLET		13

Figure 7-10. SPS Test Article Costs

7.4.3 Earth Services Antennas

The costs for development and production of the three Earth Services Antennas are presented in Figure 7-11. The 30-meter radiometer is the first unit developed, therefore, it bears a higher proportion of the DDT&E cost than the 100-meter unit. This is why these two devices are about the same cost even though one is much larger than the other.

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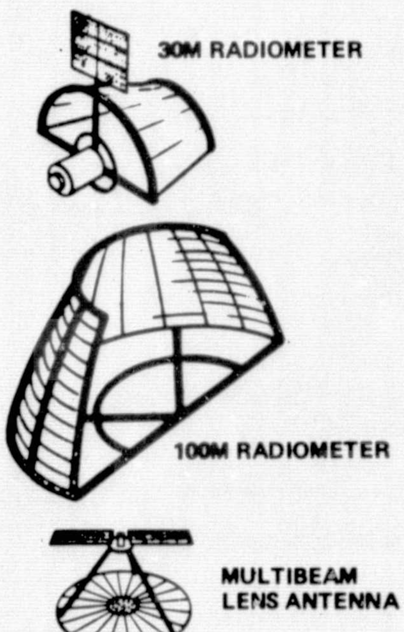
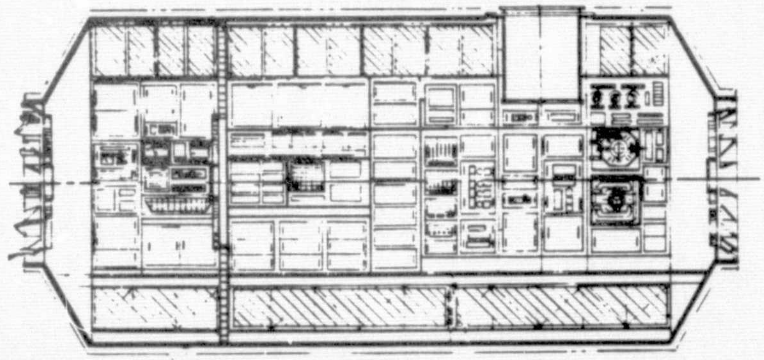


Figure 7-11. Earth Services Antenna Costs

7.4.4 Space Processing Development Facility

The costs shown by subsystem on Figure 7-12 reflect the estimated end item cost of the SPDF which is intended to be attached to the SCB to perform long duration processing and science activities supplementary to Spacelab experiment activities. The costs reflect DDT&E and Production. The end item system level integration costs have been allocated to the subsystem categories.

The cost estimates reflect a design approach which directly utilizes many Spacelab and Orbiter hardware items. This feature results in a significant cost avoidance to SPDF and the resulting combined costs to meet space processing and science mission objectives.



STRUCTURE/MECH	$33M
ECLS	34
ELECTRICAL	22
INFORMATION	15
EQUIPMENT	40
	$144M

Figure 7-12. Space Processing Development Facility Cost (SPDF)

7.5 PROGRAM COST

Figure 7-13 presents the cost of development, production, transportation to orbit, and operations for the Space Construction Base elements of the program. The cost of each of the hardware elements is indicated on the bar along with the total cost for transport and operations. The annual funding required is tabulated along the abscissa of the figure. The cumulative funding over the period up until the last of the SCB hardware elements is operational is also indicated. These data assume the Construction Shack is operational in early 1984. The effect of delaying its introduction until later would be to reduce the early year funding (DDT&E), but later year funding would be increased due to the increase in transportation costs associated with the Shuttle-tended mode of operation. From a total program cost standpoint, the net result would be a higher total cost for later introduction of the Construction Shack.

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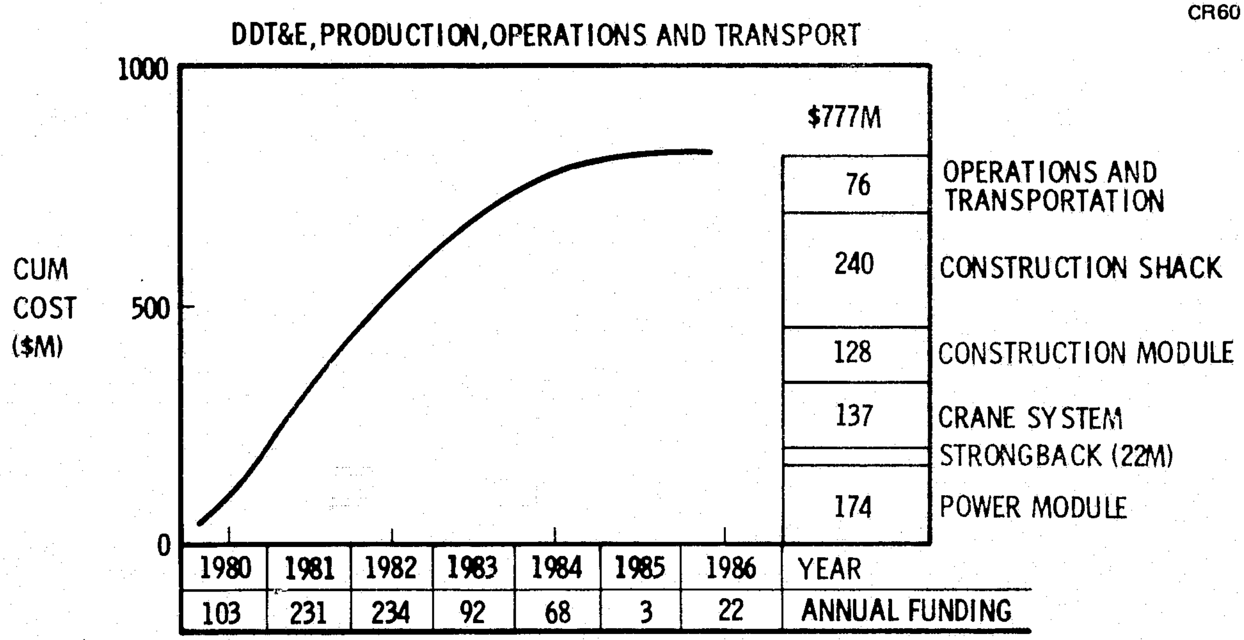

Figure 7-13. SCB Cost

The cost estimate for development, production, transport to orbit, and operations of the mission hardware for the baseline program is given on Figure 7-14.

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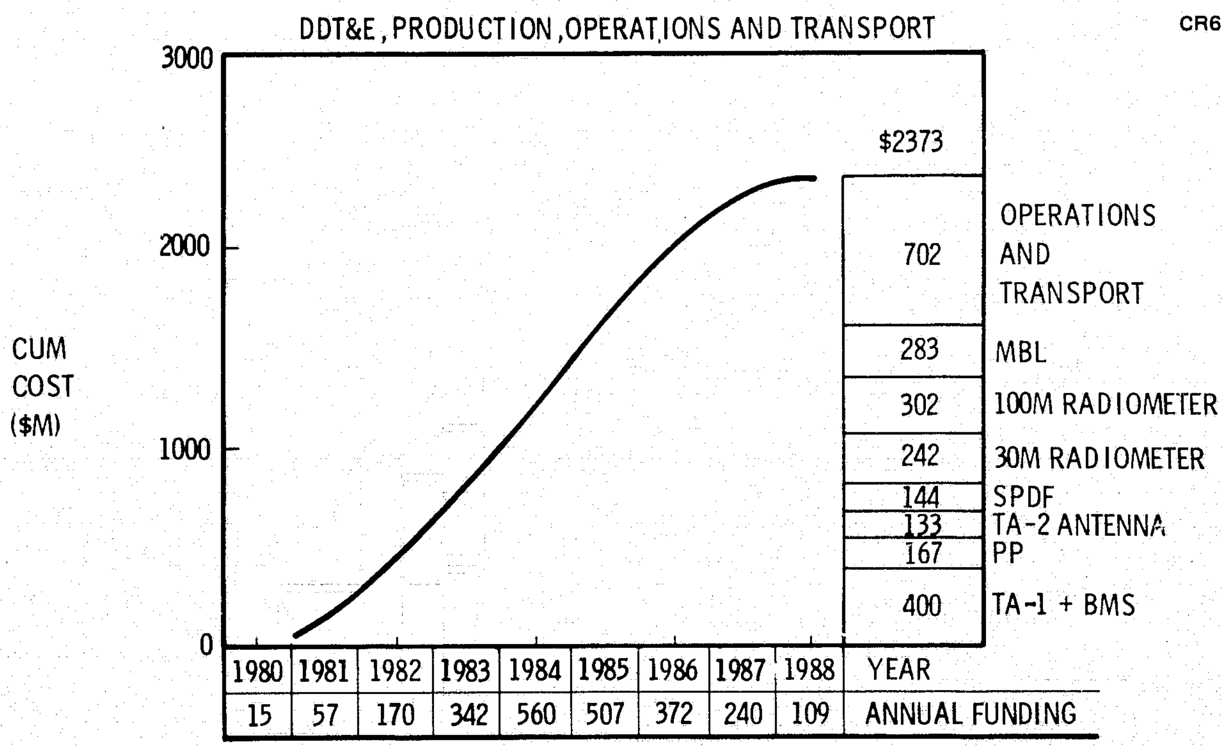

Figure 7-14. Mission Hardware Cost

The costs cover the period through the year 1988. The bar indicates the cost of each individual item with the total transportation and operations shown on the top. The cumulative funding over the period of interest is indicated on the figure.

A breakdown of the cost by mission and function is given in Figure 7-15, for the baseline program. It should be noted that some of the more ambitious mission hardware such as the dedicated space processing modules and manned geosynchronous operations were not included since it falls outside the time period indicated.

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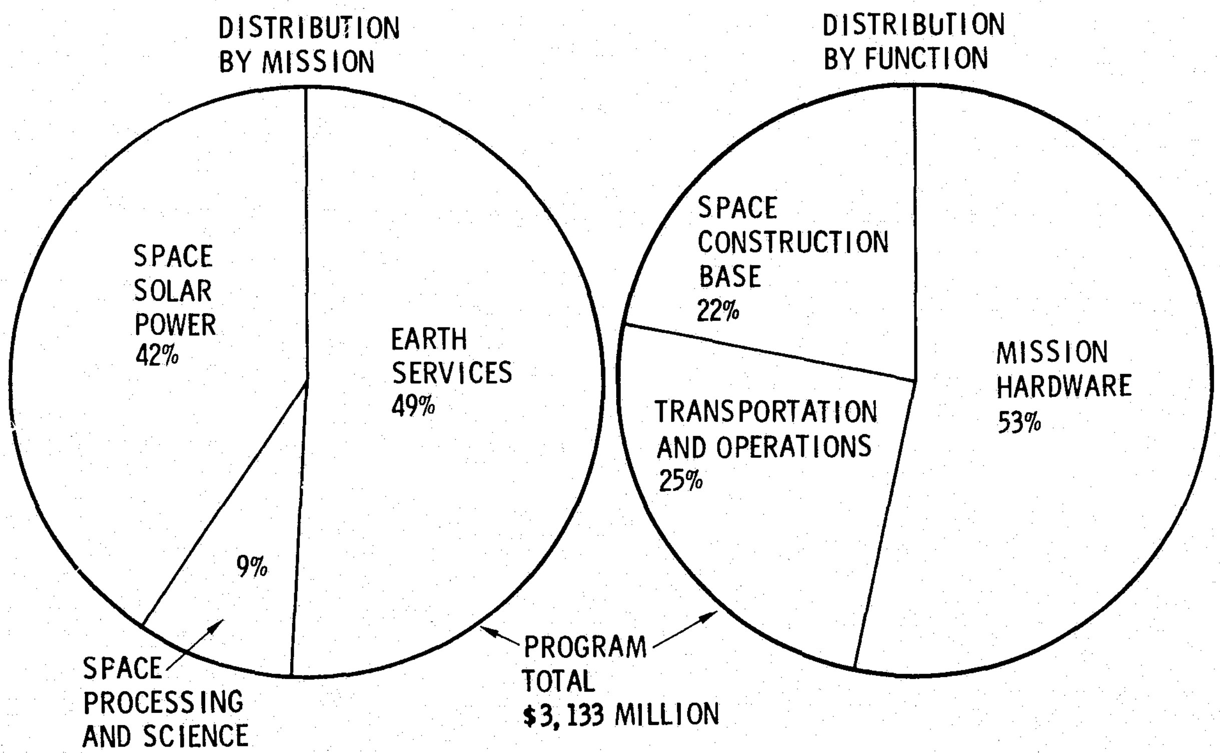

Figure 7-15. Program Cost Breakdown

7.6 PROGRAMMATIC CONCLUSIONS

Based on the results of this study, the following conclusions may be drawn:

1. The results of a study to compare costs between space fabrication and ground fabrication with on-orbit assembly or deployment (Figure 7-16) indicate that for one-of-a-kind items, similar to a power platform, deployment is probably best, on-orbit assembly becomes more cost effective after three units, and fabrication pays

off after five units. It is difficult to extrapolate these results to other types of mission hardware, but in those cases where either of the three approaches is feasible, the same general trend might be expected.

2. A habitability module is economically justified as extended period activities develop. Introduction of the habitability module to replace the Shuttle-tended mode of operation resulted in an overall reduction in program costs but somewhat increased the peak annual funding during the early years.
3. Use of Shuttle Orbiter subsystems in the Space Construction Base appears feasible and can substantially reduce the cost of the program. A large number of items were found to be usable with little or no adverse impact on the design. This not only can save development cost, but since the Orbiter will be operational throughout the operational period of the SCB, some logistics savings would also be possible.

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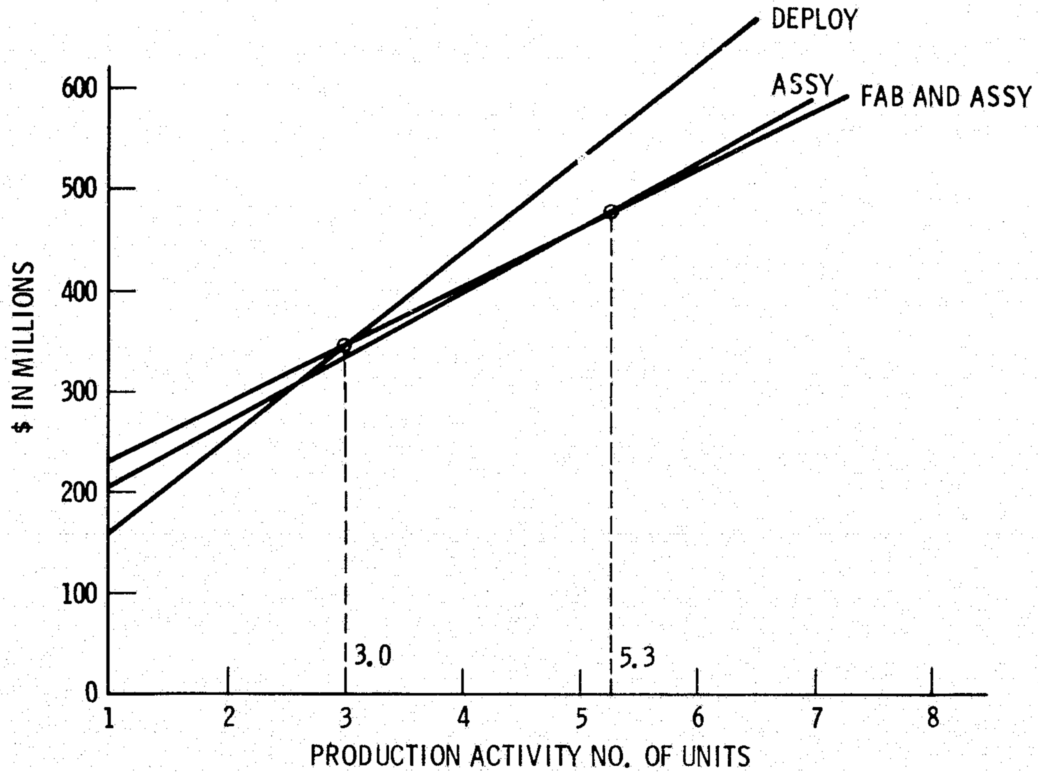

Figure 7-16. Space Vs Ground Fabrication and Assembly Production Crossover for 500 kW Power Platform

Section 8
SUBJECT REFERENCE MATRIX

The Subject Reference Matrix on the following page provides a cross-reference between study tasks, and the particular volume of documentation where the most significant portion of the subject matter of the task is discussed. In several cases, detailed descriptions of a particular task may be found in an appendix volume, whereas a synopsis of the effort will also appear in the Technical Volume.

A complete reference section, including the Table of Contents of each volume of documentation generated during the study, may be found at the end of the Appendix, Volume 3 - Supporting Data, Book 2, Section 17.

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	PART 1: EXECUTIVE SUMMARY VOL. 1	PART 1: TECHNICAL REPORT VOL. 2	PART 1: APPENDICES VOL. 3: OBJECTIVE DATA BK 1	PART 1: APPENDICES VOL. 3: OPTION DATA & COSTING BK 2	PART 2: EXECUTIVE SUMMARY VOL. 1	PART 2: TECHNICAL REPORT VOL. 2	PART 2: APPENDICES VOL. 3: PROGRAM REQMTS BK 1	PART 2: APPENDICES VOL. 3: SUPPORTING DATA BK 2	PART 2: APPENDICES VOL. 3: SUPPORTING DATA BK 2	PART 2: APPENDICES VOL. 3: COST & SCHEDULE BK 3	PART 3: EXECUTIVE SUMMARY VOL. 1	PART 3: TECHNICAL REPORT VOL. 2	PART 3: APPENDICES VOL. 3: SUPPORTING DATA BK 1	PART 3: APPENDICES VOL. 3: SUPPORTING DATA BK 2	PART 3: SUPPORTING RESEARCH & TECHNOLOGY VOL. 4	PART 3: COST & SCHEDULE DATA VOL. 5
PART 1 DEFINE AND EVALUATE PROGRAM OPTIONS																
TASK 1 OBJECTIVES	•															
1.1 REVIEW OF DATA BASE		•														
1.2 PREPARATION OF DATA SHEETS			•													
1.3 CORRELATION OF THEME ELEMENTS AND OBJECTIVES		•														
1.4 PRELIMINARY SCREENING OF OBJECTIVES		•														
TASK 2 ESTABLISHMENT OF MISSION DESCRIPTIONS	•															
2.1 PREPARATION OF MISSION SEQUENCES		•														
2.2 ANALYSIS OF LEVEL 3 REQUIREMENTS		•														
2.3 DEFINITION OF THEME ELEMENTS		•														
TASK 3 ESTABLISHMENT OF SPACE STATION PROGRAM OPTIONS	•															
3.1 ESTABLISHMENT OF GROUPS OF OBJECTIVES			•													
3.2 ANALYSIS OF CRITICAL LEVEL 4 REQUIREMENTS		•														
3.3 IDENTIFICATION OF SPACE STATION SYSTEM CONFIGURATIONS		•														
3.4 PRELIMINARY COST AND SCHEDULING OF SYSTEM OPTIONS				•												
3.5 IDENTIFICATION OF PROGRAM OPTIONS				•												
PART 2 DEFINE AND EVALUATE SYSTEM OPTIONS WITHIN SELECTED PROGRAM OPTIONS																
TASK 4 DEFINITION OF CONFIGURATIONS					•											
4.1 DEFINITION OF OBJECTIVE ELEMENTS						•										
4.2 SYNTHESIS OF DESIGN REQUIREMENTS						•										
4.3 DEFINITION OF SPACE CONST BASE AND MISSION HARDWARE ELEMENTS						•										
4.4 IDENTIFICATION AND ANALYSIS OF KEY DESIGN COST DRIVERS								•	•	•						
4.5 DEFINITION OF TRANSPORTATION SYSTEM ELEMENTS						•										
TASK 5 ANALYSIS OF OPERATIONS					•											
5.1 PREPARATION OF CRITICAL MISSION SEQUENCES						•										
5.2 DEVELOPMENT OF FUNCTIONAL/PERFORMANCE REQUIREMENTS						•										
5.3 ANALYSIS OF TRANSPORTATION SYSTEM						•										
TASK 6 SELECTION OF PRIMARY CONCEPTS					•											
6.1 DEVELOPMENT OF PROG REQMTS DOCUMENT							•									
6.2 DEVELOPMENT OF COMPARISON CRITERIA						•										
6.3 DEFINITION OF SYSTEM OPTIONS							•									
6.4 COMPARISON OF SYSTEM OPTIONS						•										
6.5 COST AND SCHEDULE DATA										•						
TASK 7 SYSTEM DESIGN											•					
7.1 SHUTTLE SYSTEMS CAPABILITY REVIEW												•				
7.2 MISSION HARDWARE REQMTS EXPANSION												•				
7.3 MISSION HARDWARE DESIGN												•				
7.4 CONSTRUCTION SYSTEM DESIGN												•				
7.5 SUPPORT SYSTEM DESIGN													•	•		
7.6 SCB SYSTEM OPTION SYNTHESIS												•				
TASK 8 REQUIREMENTS ANALYSIS											•					
8.1 MISSION HARDWARE REQMTS ANALYSIS												•				
8.2 SYSTEM REQMTS ANALYSIS													•	•		
TASK 9 PROGRAM DEVELOPMENT											•					
9.1 PROGRAMMATIC ANALYSIS																•
9.2 PROJECT PLANNING															•	

Figure 8-1. Subject Reference Matrix